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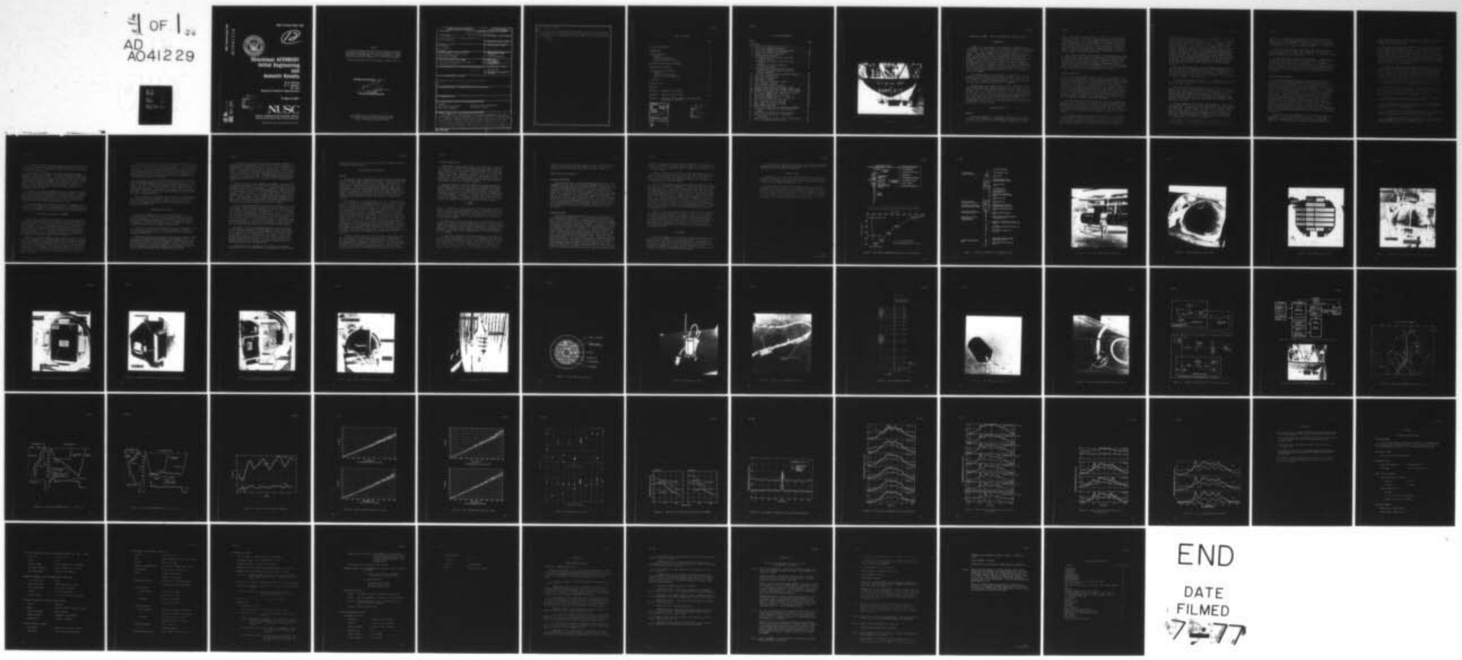

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Directional AUTOBUOY: Initial Engineering and Acoustic Results

R. S. Gozzo
R. L. Martin
N. Yen
Special Projects Department

21 March 1977

NUSC

NAVAL UNDERWATER SYSTEMS CENTER
Newport, Rhode Island • New London, Connecticut

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NUSC Technical Report 5491

PREFACE

This report was prepared under NUSC Project No. A-650-05, "Ambient Noise Characteristics Affecting Sonar and Physical Oceanography," and Navy Subproject No. SF 52-552-602-19345. The Prinicpal Investigator was R. L. Martin (Code 312) and the Program Manager, A. P. Franceschetti (SEA 06H1-4).

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The AUTOBUOY is a deep diving, self-contained, programmable data acquisition system. Three two-hydrophone systems have been built for the Navy and one of them has recently been modified to accept a long vertical array for the collection of low frequency (30 to 500 Hz) noise directionality data. The modified system, designated Directional AUTOBUOY, is designed to collect a total of 16 hr of data while hovering at as many as five different depths to 6,000 m on a single deployment. The completed system has been sea tested and

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20. Abstract (Cont'd)

the acoustic results have been analyzed using a computer algorithm designed for this purpose. Design deficiencies noted during the sea tests have been corrected, and plans for developing large horizontal arrays for this system are described.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Frontispiece

DIRECTIONAL AUTOBUOY: INITIAL ENGINEERING AND ACOUSTIC RESULTS

INTRODUCTION

AUTOBUOY is a ship launched, self-contained, programmable, free diving data acquisition system, used primarily to collect acoustic data versus depth. (See frontispiece.) Three such systems exist in the Navy to date: the initial AUTOBUOY which was designed and built by Lear Siegler in 1968 under contract to Navy Underwater Sound Laboratory (now NUSC), and two additional systems subsequently built for Navy Air Development Center for use in the Vertical Line Array Measuring (VLAM) program. At the conclusion of the VLAM program in 1973, NUSC was assigned custody of the two newer systems. The initial AUTOBUOY has been modified, ref 1, to support a long vertical array of hydrophones, in order to provide a capability to obtain low frequency ambient noise vertical directionality data as a function of depth. This report concerns itself only with the modified system which is now referred to as Directional AUTOBUOY.

The AUTOBUOY approach to directional noise measurements has the advantage of collecting significant amounts of data at up to five different depths over a short time period (single 6-48 hour dive), with an array that is completely decoupled from the ocean surface and unaffected by water current flow noise or array strumming.

The modification was completed in June 1974. Concurrent with the engineering changes made, computer algorithms were developed to translate the individual hydrophone measurements into noise directionality functions, ref 2. An operational test, ref 3, of the completed system was designed to obtain engineering performance data, and to provide an initial data base for use with the data processing technique developed. This report functionally describes the Directional AUTOBUOY, the operational performance of the system during the initial at-sea tests, changes made to the system as a result of those tests, and initial noise directionality results obtained.

SYSTEM DESCRIPTION

GENERAL

Directional AUTOBUOY is a deep-diving (6000 meters (m)), self-contained, easily deployable, programmable system designed to measure directivity of ambient noise, in the frequency range of 30 to 500 Hz,

and to record acoustic signals from 5 to 2500 Hz at five selectable depths in a deepest to shallowest sequence during any one deployment. The frequency ranges can be extended by increasing tape recorder speed and changing arrays. Directional AUTOBUOY's instrumentation records acoustic signals from a selectable set of twelve out of sixteen hydrophone channels, IRIG "B" time code, depth, temperature, and vehicle velocity on magnetic tape for processing after retrieval. An artist's drawing of Directional AUTOBUOY and a typical deployment sequence are shown in figures 1a and 1b, respectively.

The electronic control subsystem senses the desired hovering depth by comparing the signal output of a depth gauge to a programmed setting. The control system then adjusts ballast by alternately valving light and heavy fluids to the sea until neutral buoyancy is obtained. Data acquisition is then conducted according to a programmed sampling sequence, after which Directional AUTOBUOY ascends to the next programmed depth. Upon surfacing, the recovery package emits RF pulses and light flashes to signal and aid the deployment vessel in retrieval.

PHYSICAL DESCRIPTION

The Directional AUTOBUOY, figures 2 and 3, is a streamlined cylindrical vehicle 61 centimeters (cm) in overall diameter, with four lifting eyes; the structural keel and the front support structure extend slightly beyond this basic diameter. Its length from the end of the front structure to the end of the tail fairing is 3.4 m. The recovery package extends 20 cm beyond the tail fairing, and the whip antenna is 1.8 m long. The buoy's approximate weight in air in the launch condition is 660 kg, not including the array. The array cable has an overall length of 276 m with 16 hydrophones nonuniformly distributed over 237.5 m of the cable. Figure 2 is an operationally oriented line drawing of the system and figures 3 through 17 are illustrations of essential features which are further described in subsequent paragraphs.

The upper end tail fairing, has four fins for stabilizing the buoy during descent; the fairing is attached to the support structure of the program control pressure vessel, and encloses the light-fluid discharge tubing and valves, and supports the self-contained recovery package. The recovery package consists of a flashing xenon light and an RF beacon, both of which are activated when the ascending buoy breaks the ocean surface.

The support structure for the control pressure vessel is attached to the light-fluid tank (see figure 3). A split fairing encloses the control pressure vessel and its support structure. The lower half of this fairing is secured to the structure with screws and normally does not need to be removed. The upper half of the fairing is readily

removable with 1/4 turn fasteners. This half is removed to expose the control pressure vessel and the external control switch (see figure 4) and is not reinstalled until immediately prior to launch. The external diameter of the buoy at this location is 53 cm. The program control pressure vessel consists of two 36 cm inner diameter, high strength aluminum hemispheres, which are sealed to an aluminum mounting ring with O-rings. Opening the pressure vessel provides access to the single chassis to which the electronic circuit board and programming panel are attached (see figure 5). The values dialed into the programming panel by means of thumb wheel switches determine the sample depths and durations, the total recording time at each depth, and the maximum duration of the dive. Also located on the main chassis are the master timing oscillator, moisture detector, performance and environmental data, VCO's, secondary end-mission timer, and acoustic calibration timing selection.

The center body of the buoy is a 61 cm diameter right cylinder of high density syntactic foam that provides the required buoyancy and serves as the main structural member of the buoy. It supports the light and heavy fluid tanks by means of four tie-rods and circumferential fasteners, to which all other structures are attached. There are four lifting eyes embedded in the center body.

The lower or front support structure is attached to the heavy fluid tank; this supplies mounting and support for the instrumentation pressure vessel (see figure 6).

The instrumentation pressure vessel consists of two 51 cm inner diameter high strength aluminum hemispheres which are sealed in the same manner as the control pressure vessel. The housing contains the 14 track recorder and twelve hydrophone postamplifiers (see figure 7), the battery enclosure assembly, and the moisture detector (see figure 8), the acoustic calibration oscillators, patch panel for hydrophone inputs, and power conditioning circuits for the recorder and electronic circuit boards (see figure 9).

The front support structure also has the mechanical strain relief termination point for the array and the lead shot descent weight assembly (see figure 10). The array cable (see figure 11) is 2.54 cm in diameter with 18 triads secured around a 0.56 cm 7 x 19 stainless steel jacketed strength member; the overall outside jacket is neoprene (see figure 12), with blocking material molded in at each strength member (see figures 10 and 11), breakout (see figure 14), and the two molded electrical penetration connectors (see figure 6).

The sixteen, ITC-8021B hydrophones (see figure 13) are 10.8 cm in diameter and 19.8 cm long overall, including the cage and clamps, with 61 cm, four conductor cable molded to the top of the hydrophone boot.

Each cable is terminated with a molded pressure proof connector (see figure 14). The hydrophone preamplifiers are constructed with pressure compensated electronic components. Figure 15 identifies the location of each hydrophone in the array. The weight of hydrophones is supported by a stainless steel strain relief in the array cable.

To achieve neutral buoyancy of the array, high density syntactic floats are attached to the cable during deployment. The flotation is 36 cm in diameter by 61 cm long, and is attached to the cable with molded polystyrene cable grips (see figure 16).

At the bottom of the array, a tensioning weight is added to provide tension along the length of the array to ensure that the array is vertical during all phases of the dive (see figure 17). The weight is attached by using a magnesium disk secured in a stainless steel assembly. The disk thickness is selected to last for the entire programmed dive time, plus eight hours. This feature ensures that the buoy will ascend to the surface even if the heavy fluid is not released at the end of the mission.

OPERATIONAL CHARACTERISTICS

Directional AUTOBUOY records water temperature, depth (pressure), vertical velocity of the buoy through the water, time, and twelve channels of acoustic information. It can be programmed to remain submerged for up to 48 hours and to record data on magnetic tape, continuously or intermittently for a total time of eight hours at 1 7/8 in./sec (4.76 cm/sec) or 16 hours at 15/16 in./sec (2.38 cm/sec). The frequency response is from DC to 2,500 Hz at 1 7/8 in./sec and DC to 1,250 Hz at 15/16 in./sec. Sampling intervals can be selected to cover descent and ascent modes, as well as the five hovering modes, and the number of samples recorded during any one mode can vary from 1 to 48. A calibration signal of binary random noise mixed with a 1.0 kHz sine wave is injected at the beginning of the first data sample. This signal is injected in series with the postamplifier and recorded on the magnetic tape to permit deriving absolute acoustic sound pressure levels. A crystal controlled oscillator which has an accuracy of $\pm$ 10 ppm provides the basic timing frequency of 1.0 kHz for the entire system. Temperature, depth, vehicle velocity and other equipment specifications are contained in appendix A.

Twelve of the sixteen hydrophones are selected to be recorded on twelve channels of the fourteen channel recorder (see figure 18a). To provide for a wide range of acoustic signals, each post amplifier is adjustable in five dB steps from +30 dB to +60 dB. Water temperature,

vehicle depth and velocity are multiplexed on one channel. The timing signal uses "IRIG B" format with a 1.0 kHz carrier frequency and is recorded on the remaining channel.

When deployed, Directional AUTOBUOY assumes a vertical attitude with the RF antenna in the uppermost position. It descends rapidly to the preset maximum depth, where the lead shot descent weight (see figure 10) is jettisoned. The lead shot weight provides a velocity of up to 1.2 m/sec during descent. Depth control of AUTOBUOY is then accomplished by the alternate valving of perchlorethylene and mineral spirits to the sea. These two fluids have, respectively, a specific gravity greater than and less than sea water. Buoyancy is thus adjusted closely about a neutral value in response to pressure error, and velocity error signals derived from the self-contained instrumentation.

The heavy fluid and light fluid tanks are vented to the sea. Discharge tubing is located so that the difference in specific gravity will cause the fluid to gravitate to the sea when the associated discharge valve is opened. The light fluid discharge tube extends upward from the light fluid tank (see figure 2) and the heavy fluid tube extends downward from the heavy fluid tank when the system is operationally oriented. This method minimizes the possibility of noise generation by eliminating any need for pumps. As fluid is released, it is replaced by sea water entering the tank through the open vent. Figure 18b is a block diagram of the Directional AUTOBUOY control and sensor system.

Programming of Directional AUTOBUOY is accomplished with digital switches that control initial descent to the deepest depth, ascent to as many as four shallower depths in sequence, and final ascent to the surface. At each of the five hovering depths, individually selectable hovering periods and data acquisition programs may be chosen.

Safety features to abort a dive and cause Directional AUTOBUOY to return to the surface if a malfunction occurs include:

1. A leak detector (moisture sensor) located in the instrumentation housing, and control housing that controls the heavy fluid discharge valve to gain positive buoyancy.

2. A secondary end-mission timer that causes the heavy fluid valve to open at a preset time. The purpose of this timer is to end the dive if the basic programmer fails to initiate ascent to the surface.

3. A magnesium valve whose disk corrodes, over a selectable period of time, to dump heavy fluid. The amount of corrosion time involved is determined by the thickness of the disk selected.

4. A magnesium disk connecting a weight to the bottom of the array will corrode 8 hr after the programmed dive termination time, thereby releasing the weight and permitting the buoy to ascend even if the heavy fluid has not been released.

An RF signal and a flashing xenon light announce Directional AUTOBUOY's return to the surface. The recovery package is completely independent of the other systems. A pressure switch keeps the package deactivated below the water surface, and a gravity switch permits operation only when Directional AUTOBUOY is in a vertical position. The RF transmitter will operate for 48 hours and the flashing light for 72 hours. The RF signal has been received at ranges in excess of 32 kilometers (km), and the light can be seen at night at about 6 km depending on the sea state.

Deployment of Directional AUTOBUOY is normally scheduled so that it will return to the surface an hour or two before daybreak. A shipboard radio direction finder is used to detect the buoy's return to the surface and to direct the recovery ship to the general area, where the flashing xenon light pinpoints the location. With the coming of daybreak, the buoy is retrieved aboard the recovery ship.

Detailed equipment specifications for sensors, instruments, and fluids are given in appendix A. Appendix B discusses modifications made to Directional AUTOBUOY as a result of deficiencies uncovered during the at-sea test described in a later section of this report and in appendix C.

DEPLOYMENT AND RETRIEVAL PROCEDURES

Once the initial condition of readiness is established, there are no elaborate adjustments necessary to prepare Directional AUTOBUOY for a specific mission. Establishing the initial condition involves ballasting for proper buoyancy, setting valve timing circuits for efficient depth changes, setting valve threshold levels and system hysteresis relative to depth error and buoy velocity, and setting the hover velocity detector circuit. These "tune-ups" are predicted on the results of a few performance dives, and once established, the settings remain unchanged unless performance modifications are desired.

Ideally, Directional AUTOBUOY's weight should be such that the buoy will be neutrally buoyant when the descent weight is released. Because Directional AUTOBUOY's preprogrammed control system adjusts the buoyancy about neutral, to make it descend, ascend, or hover, initial ballasting is not as critical as might be supposed. The endurance of the control system, however, is determined by the amount of fluids carried; therefore, analysis of the behavior of Directional AUTOBUOY on several dives might indicate the desirability of adjusting the buoyancy in the launch condition.

The ships crane or davit is used to lift Directional AUTOBUOY by a harness attached to four lifting eyes (see figure 19). Also attached to this harness is a 45 m tag line used during recovery. The ship is headed into the sea at slowest speed possible and the array is deployed from its reel and connected to the buoy; the buoy is then swung over the side and lowered into the water. When the buoy reaches the water surface, the quick-release hook is pulled, allowing Directional AUTOBUOY to descend freely with the harness attached.

For retrieval, the ship is brought alongside the Directional AUTOBUOY and a grappling hook is thrown over the buoyant tag line. The tag line is then bent around another line which is reeved through the crane sheave. The unit is lifted slowly from the water, swung aboard and lowered onto its cradle. While the buoy is being lifted, the weight of the array is removed by taking in on a line attached to the array transfer point. After the buoy has been secured and the array disconnected, the array is brought onboard.

On deck, the buoy is thoroughly inspected, and the remaining fluids and salt water are released from the tanks. The buoy is then wheeled into a sheltered area (tents, vans, and deckhouses have been used), where the instrumentation housing is opened and the magnetic tape removed for data processing.

OPERATIONAL TEST RESULTS

Directional AUTOBUOY received its first performance tests in December 1974, ref 3. These tests consisted of handling, ballasting, pressure and operational trials from USNS BARTLETT (T-AGOR-13) during the period 11 through 18 December 1974 at a site 300 nmi due east of Cape Canaveral; the test site chosen is shown in figure 20. Appendix C describes the at sea effort and problems encountered.

The test site was chosen for deep water, near port convenience, and for expected mild weather and seas. With the exception of two days (15, 16 December) during which sea state ranged from 3-5, weather was suitable for testing.

System overboarding tests had been executed prior to departure from New London, and facilitated the handling of the equipment at sea. The initial ballasting tests indicated that the array was neutrally buoyant as planned but that the Directional AUTOBUOY itself was 35 pounds (16 kgm) less buoyant than expected (5 pounds or 2.3 kgm negatively buoyant); this was temporarily corrected by adding additional buoyancy to the "nose" of the main frame to permit continuation of testing.

The pressure test consisted of lowering Directional AUTOBUOY to a depth of 1500 m (approximately 2200 $lbf/in.^2$ or 15 MPa of pressure) by a hydrographic wire and then returning it to the ship to determine if either of the pressure vessels leaked. For this test, a heavy weight with a corrodible link was added to the modified buoy to ensure eventual return to the surface if only the lowering wire failed, and the Astroscience tape recorder in the main instrumentation pressure housing was replaced by an equivalent weight. No water leakages occurred at any of the penetration connections, or at any of the seals for the pressure spheres.

The first free dive test occurred on 13 December. The system was programmed to descend to 600 m, hover while collecting data for a 2 hour period, and then ascend to the surface. No effort at ship quieting was attempted because it was considered more important to remain at the dive site ready to get under way in case a problem occurred. The actual dive sequence is shown in figure 21. The main figure displays Directional AUTOBUOY depth vs time. The bottom figure shows buoy velocity vs time and the left hand figure contains sound speed and water temperature vs depth. After reaching the planned depth, Directional AUTOBUOY hovered momentarily and then slowly descended to a depth of 1600 m before the heavy fluid valve opened causing it to rise to the surface.

The need for determining the cause of the buoy malfunction and subsequent poor weather conditions delayed the follow-on 2-depth test until 17 December. During the intervening period, possible causes of failure were determined and corrected. (See appendix C.) For the 17 December test, the buoy was programmed to collect data for an hour at each depth, then to release its heavy fluid and return to the surface. During this period, BARTLETT moved off 8 km and went to quiet ship conditions. Again the buoy went to its hovering condition and slowly drifted deeper, as shown in figure 22. It received the command to ascend to the second hovering depth and initiated ascent but was unable to release fluid quickly enough and never reached the second (shallow) depth station.

In addition to the lack of adequate buoyancy, the basic problem encountered after shipboard electronic corrective measures were taken was the inability of the Directional AUTOBUOY to release heavy fluid fast enough and for a long enough time. It was not possible to modify the equipment at sea to accomplish this basic change. In any event, BARTLETT was scheduled to be in port no later than 20 December, permitting no more than one additional test day. Since these tests, the problems observed at sea and other less serious problems have been diagnosed and corrected. (See appendix B.)

Although these tests did not meet all objectives, an adequate amount of ambient noise uncontaminated by the deployment vessel, and at

relatively deep depths was collected for testing the computer algorithm developed for data reduction.

NOISE DIRECTIONALITY RESULTS

GENERAL

The acoustic data for determining the vertical noise directionality function for this area was taken on 17 December at a depth of about 2400 m which is in the sound channel at this location. From figure 22, it is noted that the sound speed at this depth is 1507 meters per second (m/sec) and is 1535 m/sec at the near surface maximum; additionally, by extrapolation, the near bottom sound speed at 4900 m is approximately 1552 m/sec. Therefore, according to Snell's law, noise energy from surface shipping would arrive at the Directional AUTOBUOY depth at angles greater than 11° from the horizontal (or less than -11°) and energy arriving at angles greater than 14° (less than -14°) would be bottom limited.

While bottom loss was not measured at this site, it might be reasonable to assume that at low frequency these losses are small for grazing angles out to 10° which corresponds to 24° at AUTOBUOY depth. Therefore the directionality function would have a fairly broad peak from about 11° to 24°, falling off rapidly at angles less than 11° and more slowly for angles greater than 24°. A further complication arises, however, due to the nearby bathymetry (see figure 20) which show strong bottom slopes which could result in a "megaphone" effect for noise radiating from ships traversing those slopes. This effect results in reflecting surface ship noise into the sound channel at relatively low angles; this would tend to "fill in" the directionality function at angles between 11° and -11°. Because this test was more of an engineering trial than a measurement test, no attempt was made to observe shipping in the area, and therefore the preceding comments cannot be substantiated. However, the comments are important to the extent that they are reasonable in themselves, and can be used as guidelines to judge the reasonableness of the results and thereby the computer algorithm by which they were obtained.

A concern in data reduction is the interchannel phase fidelity that can be achieved with the Astroscience tape recorder. Degradation of this phase fidelity is due to lack of knowledge of the static skew of the record and of the reproduce system, where they are different, and to poor dynamic skew characteristics of the recorder. Prior to processing the data, it was necessary to determine and correct the static skew difference and to assess the effect of the dynamic skew on the results.

TAPE SKEW DETERMINATION

Measurements of phase angle changes in recorded signals caused by the dynamic skew of the tape have been analyzed in order to determine if a correction is needed in processing the AUTOBUOY data for ambient noise directionality. Figure 23 is the time series of the phase angle change between signals recorded on channels 1 and 11 at 1 7/8 in./sec recorder speed. Those curves indicate that tape movement reaches a steady state in less than three seconds. The periodicity of tape skew fluctuation is about two seconds and the peak to peak value of phase angle change at 500 Hz is less than 10 degrees.

Figures 24 and 25 result from comparing the average phase angle change between channels 1 and 11 for signal recorded on the different portion (beginning and end) of the tape at two different tape speeds (1 7/8 and 15/16 in./sec). No appreciable difference in phase angle change has been observed with position on the tape, but the magnitude of phase angle change is increased by a factor of two when the tape speed is reduced by one-half. In general, the phase angle change increases linearly with frequency as indicated in figures 24 and 25 and it can be expressed in terms of microseconds using the following relation:

$$\tau = \frac{\theta}{.36\ f} ,$$

where τ is tape skew in microseconds, θ is the phase angle change in degrees, and f is the signal frequency in kHz. In the particular cases shown, the curves deviate slightly from linearity above 250 Hz for 15/16 in./sec and 500 Hz for 1 7/8 in./sec. The cause for such deviation is due to the phase response of the filtering network in the system used to obtain these results.

The mean of tape skew (static skew) and its corresponding rms value (dynamic skew) for all recording channels with respect to channel one are summarized in figure 26. The data points represented by various symbols result from different reference signals for measuring playback head-stack alignment. These data indicate that the measured tape skew depends on how the reproduce head-stack is aligned as well as how the record head-stack is aligned.

As indicated in figure 26b, the largest dynamic tape skew measured is less than 20 microseconds. For the 237.5 m AUTOBUOY array whose upper frequency range is designed to be 125 Hz, such dynamic skew will cause a phase angle error of less than 1 degree, which can be neglected in array processing. However, the static skew varies over a much greater range and correction for the resulting error introduced in phase angle is needed. Because the tape skew is also related to how the play back head

stack is aligned, the calibration signal for static tape skew measurement must be recorded on the same tape as the data so that the same reference can be used for skew correction during data reduction.

AMBIENT NOISE DATA REDUCTION

Omnidirectional Noise

Omnidirectional noise was processed from the output of the first hydrophone (the one closest to Directional AUTOBUOY) in the array. The 1/3 octave band spectrum levels obtained from dives #1 and #2 are shown in figure 27 during both a diving (.25 to .4 m/sec) and a hovering condition ($<$ 0.1 m/sec) for each dive. The noise spectrum level is higher by 3 to 15 dB for Directional AUTOBUOY in the diving state than that in the stationary state. In general, both dives have similar noise spectra, but the noise level for dive #2 is higher than that for #1, particularly in the frequency range below 50 Hz. Also, shown in figure 27 are the calibration equivalent pressure levels (dotted curve) for each dive obtained by processing the pseudo random noise plus 1 kHz sine wave calibration signal in 1/3 octave bands. Note that this signal is well behaved on dive #2 and has an equivalent pressure level of +70 dB//1uPa/Hz.

Directional Noise

The optimum beamforming method, ref 4, has been used to estimate the ambient noise directionality. Noise data from all hydrophones, as well as the pseudo random noise calibration signal, from the recording tape of dive #2 have been low pass filtered and digitized with a sample rate of 512 Hz to prevent aliasing of the data. A series of fast Fourier transforms of the digitized data were obtained and operated on to form a correlation matrix for the estimation of the directionality function. The calibration signal, being in phase on all channels, simulated a broadside plane wave and was used to evaluate the directionality algorithm. Figure 28 shows the estimated directionality function (solid line) and the corresponding raw beamformer output (dash line) for the calibration signal in a 1/3 octave band at 50 Hz. Comparison of these curves indicates that the algorithm is effective and that the tape skew correction is valid. 0.1 percent uncorrelated noise has been added to each hydrophone output during this process in order to avoid an ill-conditioned matrix for the computation algorithm which occurs when all elements of the matrix are equal to the same value (in this case unity). The level of the directionality function in figure 28 has been adjusted

so that its spherical integration will correspond to the calibration equivalent spectrum level (70 dB) shown in figure 27. A different scale is applied to the raw beamformer output in order to put the two curves in the same figure.

Figure 29 examines the stationarity of the noise directionality by processing the noise data over 15, 30, 60, 120, 240 and 360 second segments in the 50 Hz band. The computed results for both the noise directionality and raw beamforming output appear to be stationary for averaging times of 60 seconds or more.

The noise directionality in 1/3 octave bands for frequencies from 18 to 125 Hz is displayed in figure 30. Strong signal peaks which become more noticeable with increasing frequency occur in the -38, -18, 12 and 30 degree directions. At present, no attempt has been made to explain this phenomenon. The long term variation of noise directionality during Directional AUTOBUOY dive #2 is shown in figure 31. These curves result from processing one minute data segments in 50 Hz band at the indicated times. At T equals 01:35:00 hours, Directional AUTOBUOY was still in a diving state, and the overall noise was high, as indicated in figure 26, but as noted in the first curve, it was not spatially correlated; only one peak at -12 degrees is observed. The remaining curves were obtained while the Directional AUTOBUOY was in the hovering mode, and it is noted that the general features of the noise directionality pattern remains unchanged with time.

Figure 32 results from comparison of the effect of the uncorrelated noise on the noise directionality estimation. Three cases are analyzed with uncorrelated noise added in the amounts of 0.001, 0.01 and 0.10 percent of the omnidirectional noise level to each hydrophone output. This added uncorrelated noise does not alter the angular distribution of the noise field as indicated in figure 31; however, the noise level, particularly the background noise, increases. The total noise level from spherical integration for those three cases are 89.10, 89.83, and 91.02 dB, respectively.

CONCLUSIONS

Directional AUTOBUOY has been modified to permit deployment of long vertical arrays to measure the vertical directionality of noise over a broad frequency range for up to five depths during a single deployment. Initial at-sea tests indicated some design deficiencies which have since been corrected (appendix B). While all the planned tests of ref 1 could not be completed, an adequate amount of acoustic data was collected to permit testing of the data reduction algorithm.

The results of the data analysis indicate that Directional AUTOBUOY together with the data reduction algorithm provide a useful system for obtaining noise directionality measurements.

CURRENT EFFORTS

Although a very specific array has been developed for these tests, AUTOBUOY is adaptable to many different designs. An alternate design consisting of 36 elements multiplexed on the 12 tape channels in groups of three has been developed (see reference 5).

Design concepts for horizontal super-directive arrays of 12 elements having apertures of 60 to 100 ft for deployment with the Directional AUTOBUOY exist. Super-directive array performance is greatly affected by locally generated uncorrelated noise. Because AUTOBUOY is completely uncoupled from the ocean surface and moves as a unit under the influence of ocean currents (thereby eliminating flow noise), it is expected that the amount of locally generated noise will be negligible.

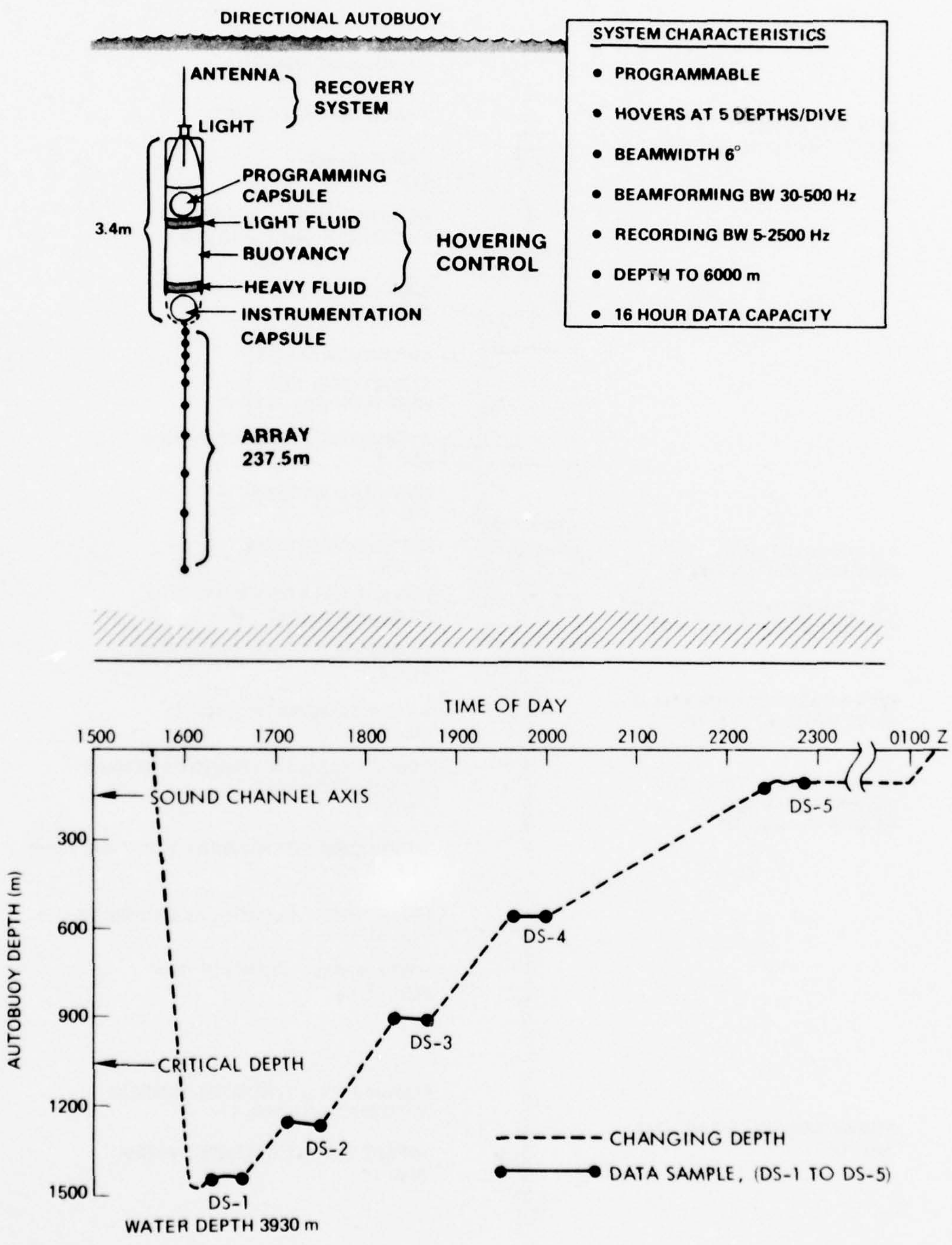

Figure 1. Directional AUTOBUOY Characteristics and Deployment

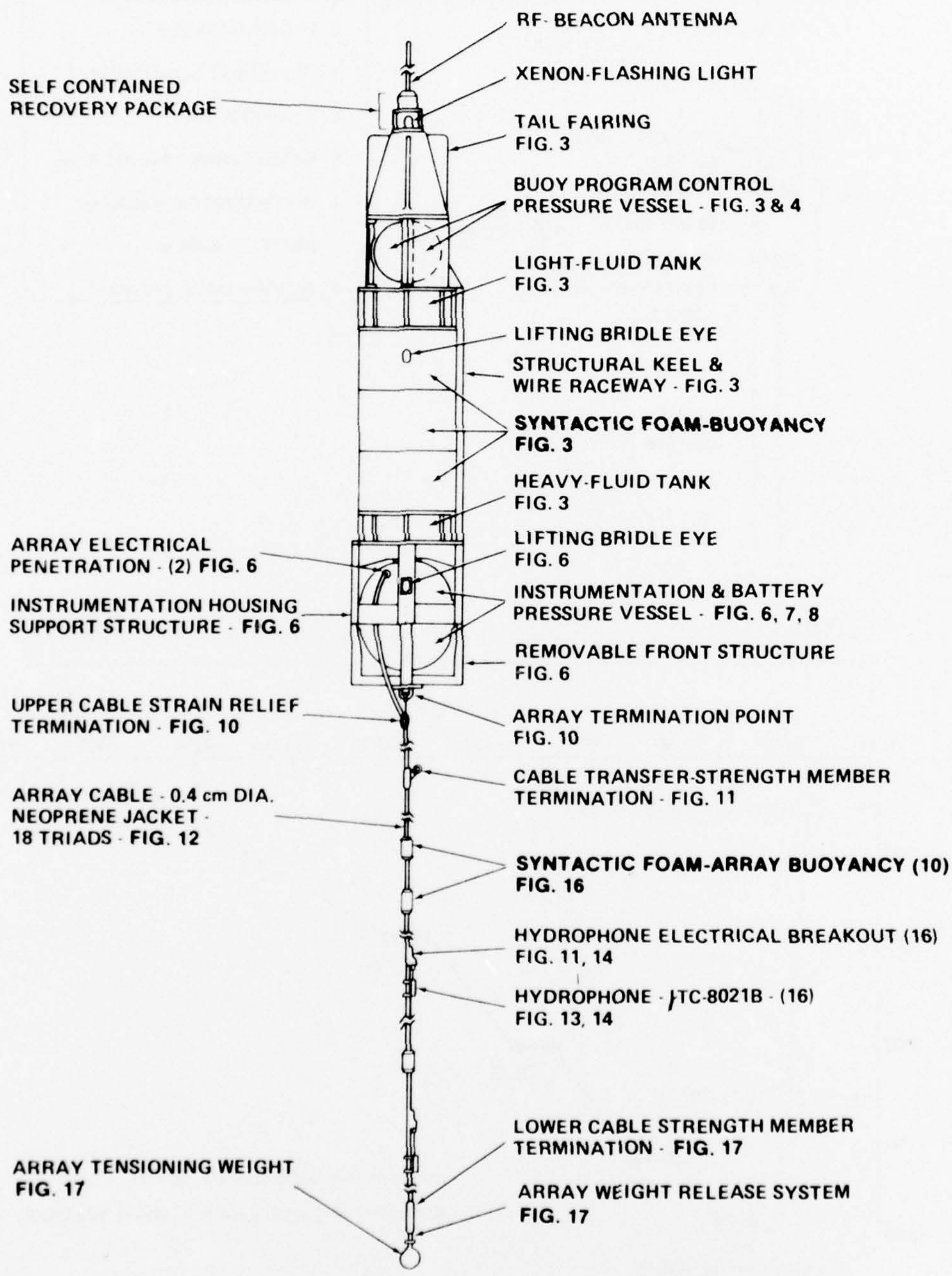

Figure 2. Directional AUTOBUOY with Hydrophone Array

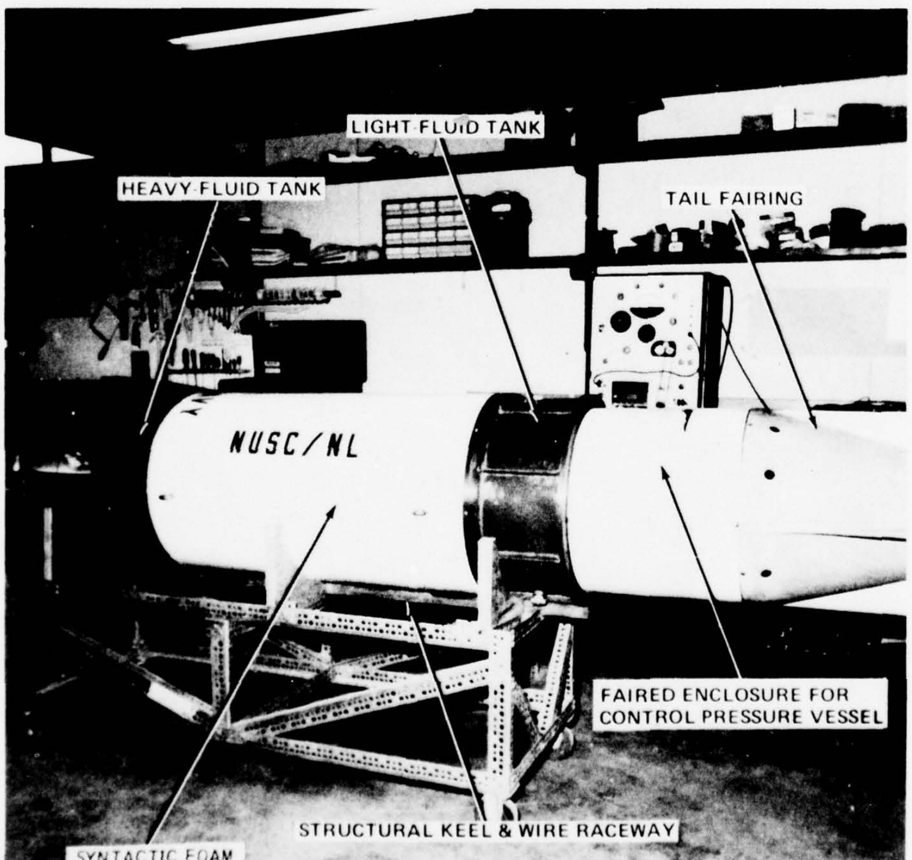

Figure 3. Directional AUTOBUOY Major Components

Figure 4. Program Control Pressure Vessel

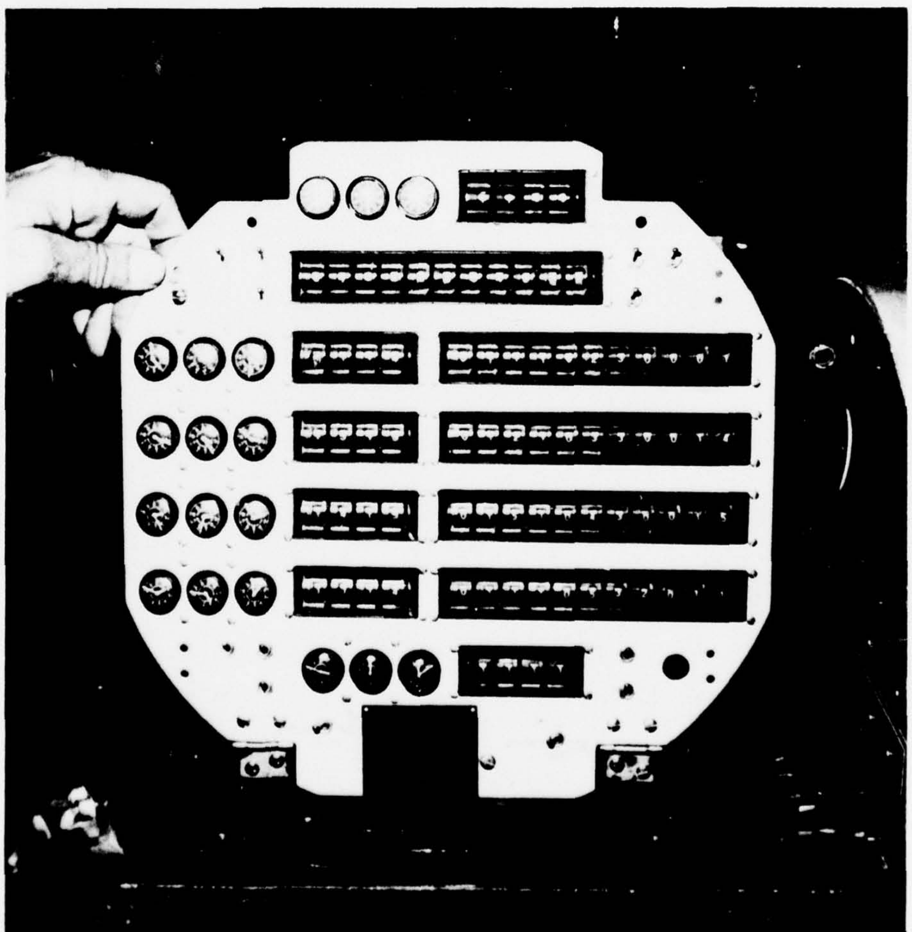

Figure 5. Buoy Program Control Panel

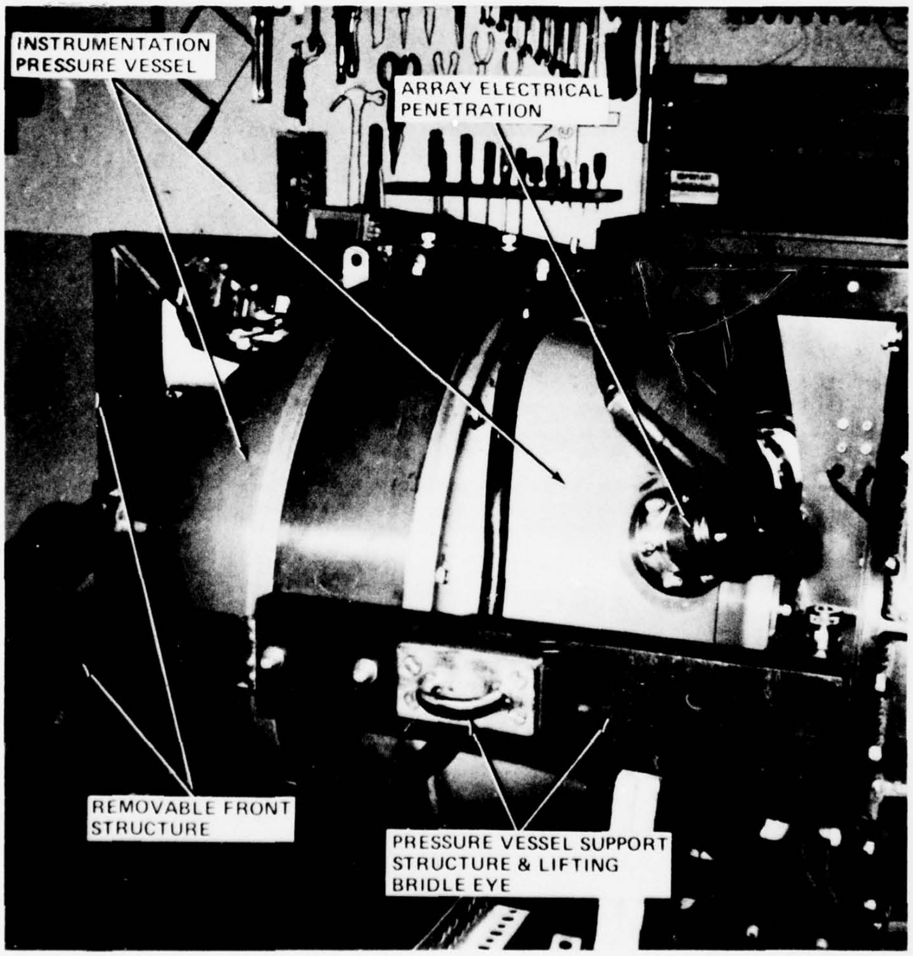

Figure 6. Instrumentation Pressure Vessel and Front Structure Details

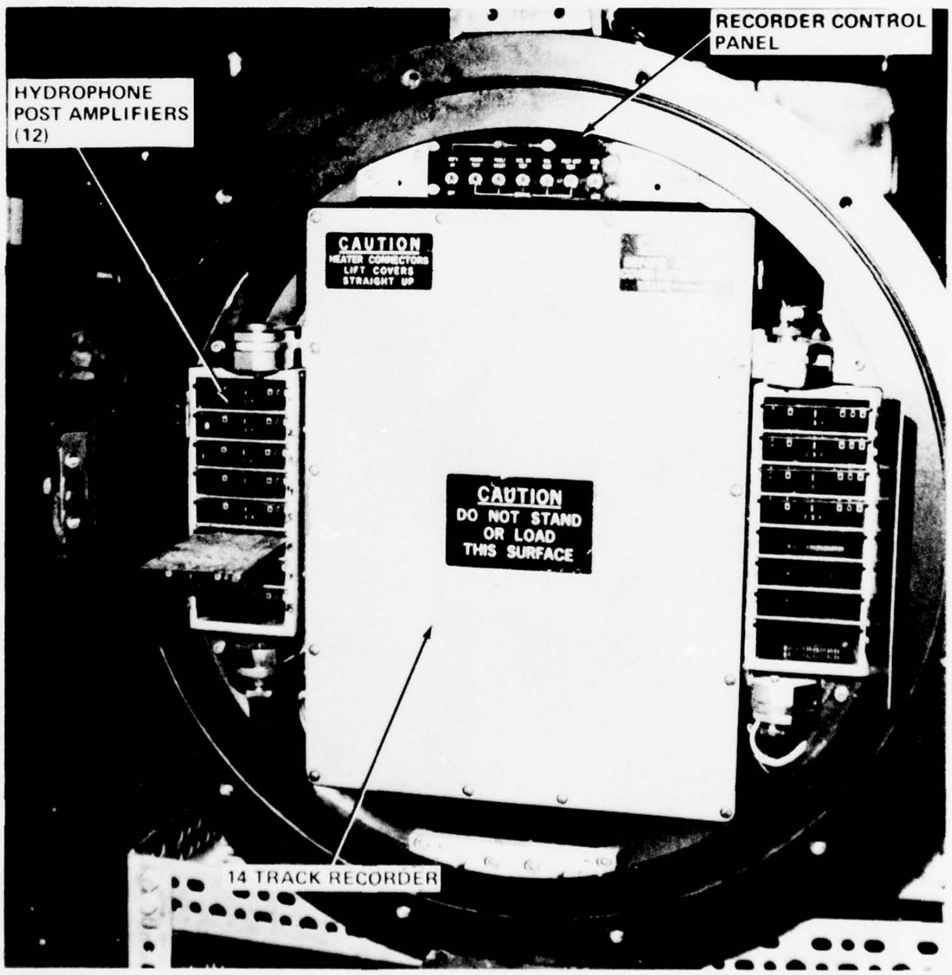

Figure 7. Instrumentation Pressure Vessel with Cover Removed

Figure 8. Instrumentation Vessel with Battery Enclosure Installed

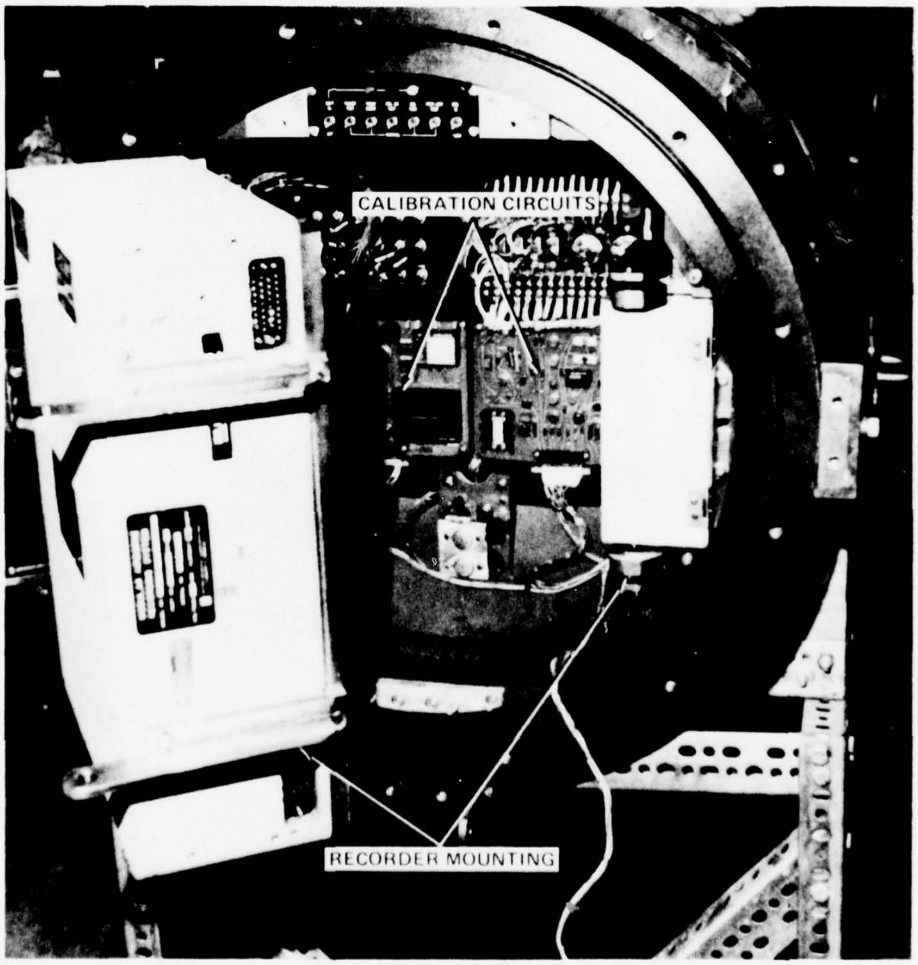

Figure 9. Instrumentation Pressure Vessel with Cover Removed Showing Calibration Circuits and Recorder Mounting

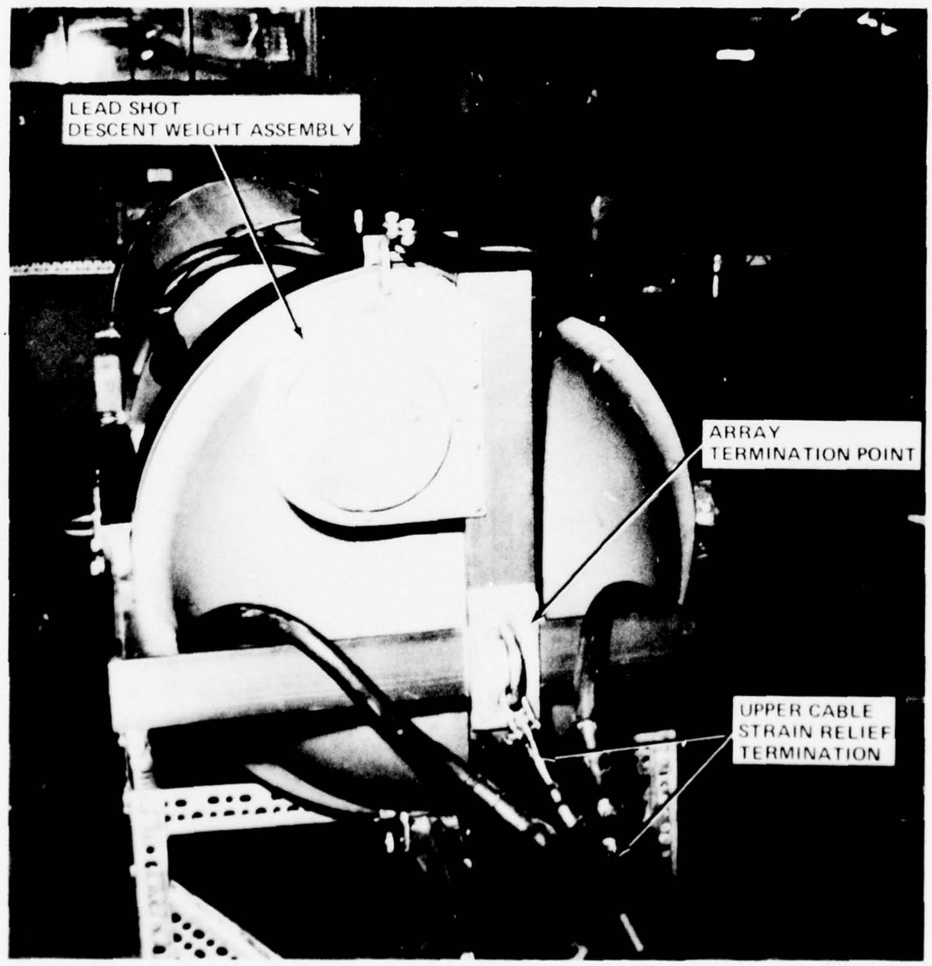

Figure 10. Buoy, Array Termination and Strain Relief Details

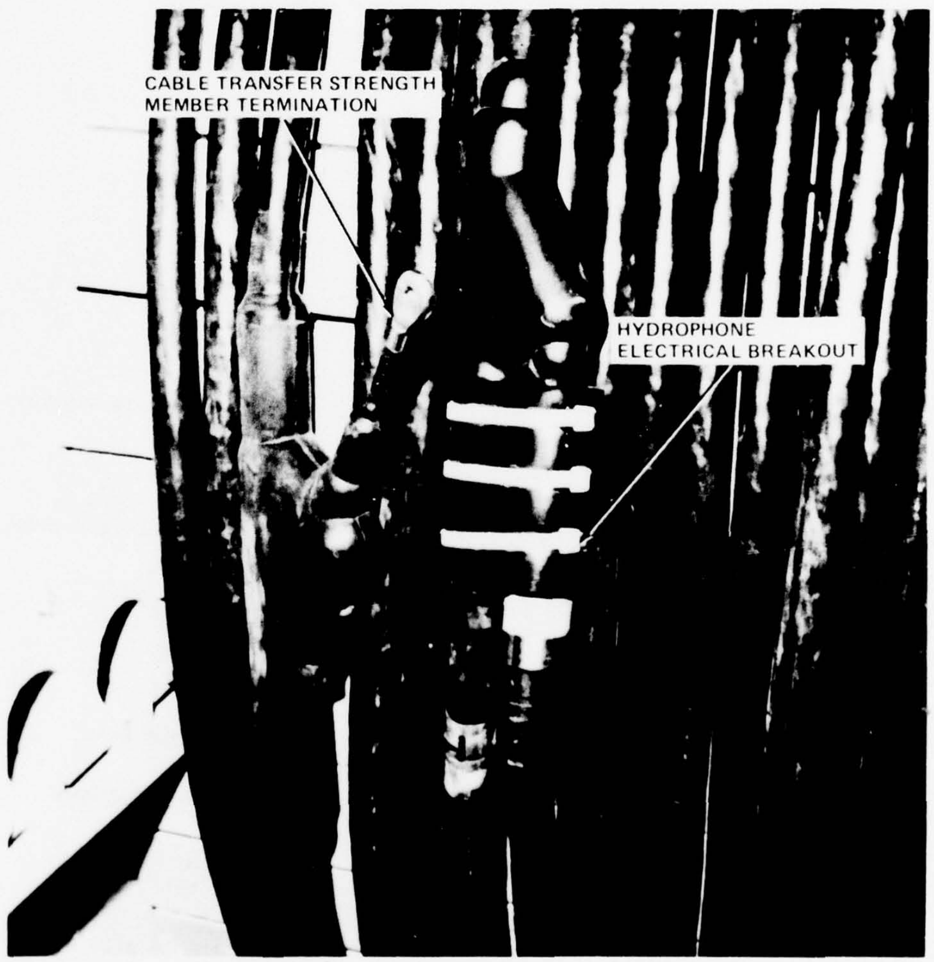

Figure 11. Array Cable Transfer Point

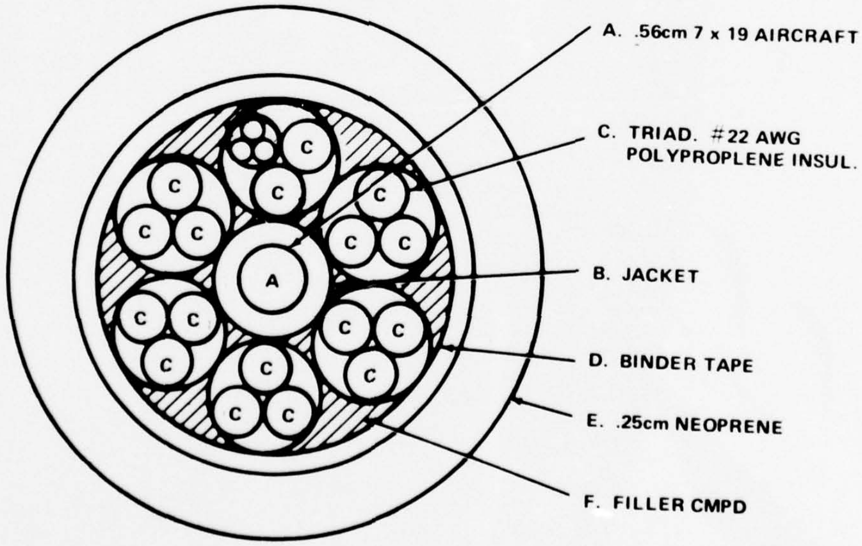

Figure 12. Array Cable Construction

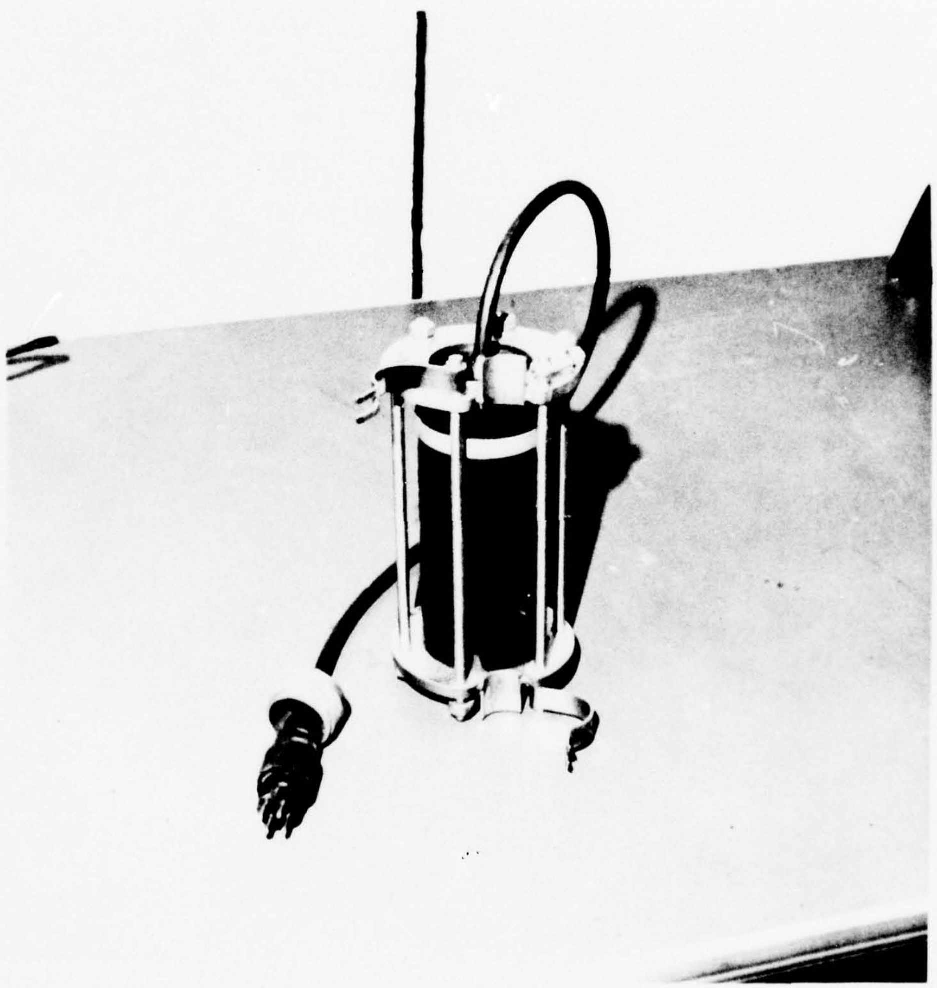

Figure 13. Hydrophone ITC-8021B

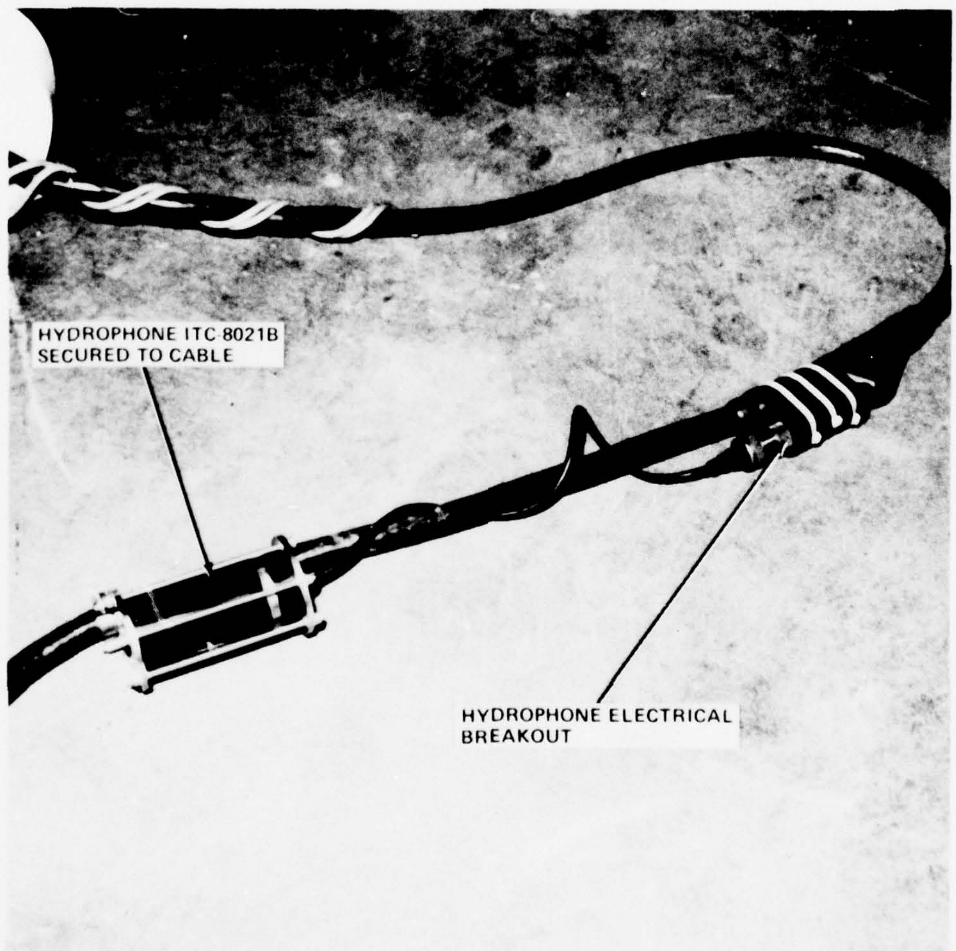

Figure 14. Array Cable with Hydrophone Attached

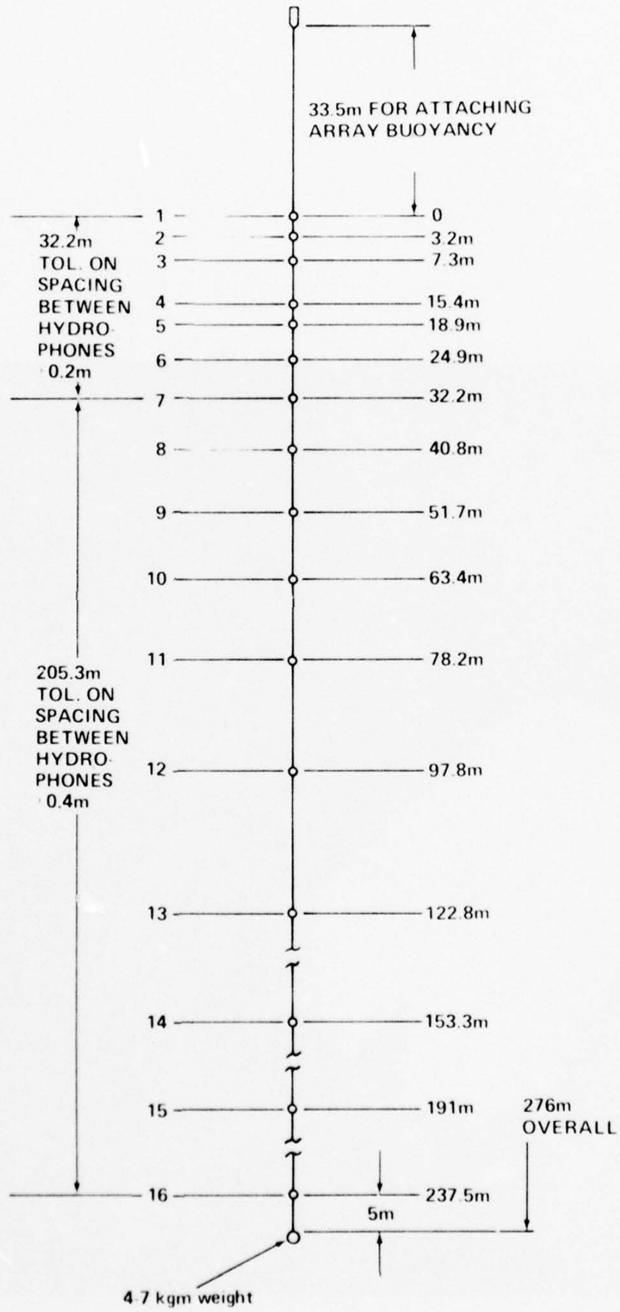

Figure 15. Array Hydrophone Location

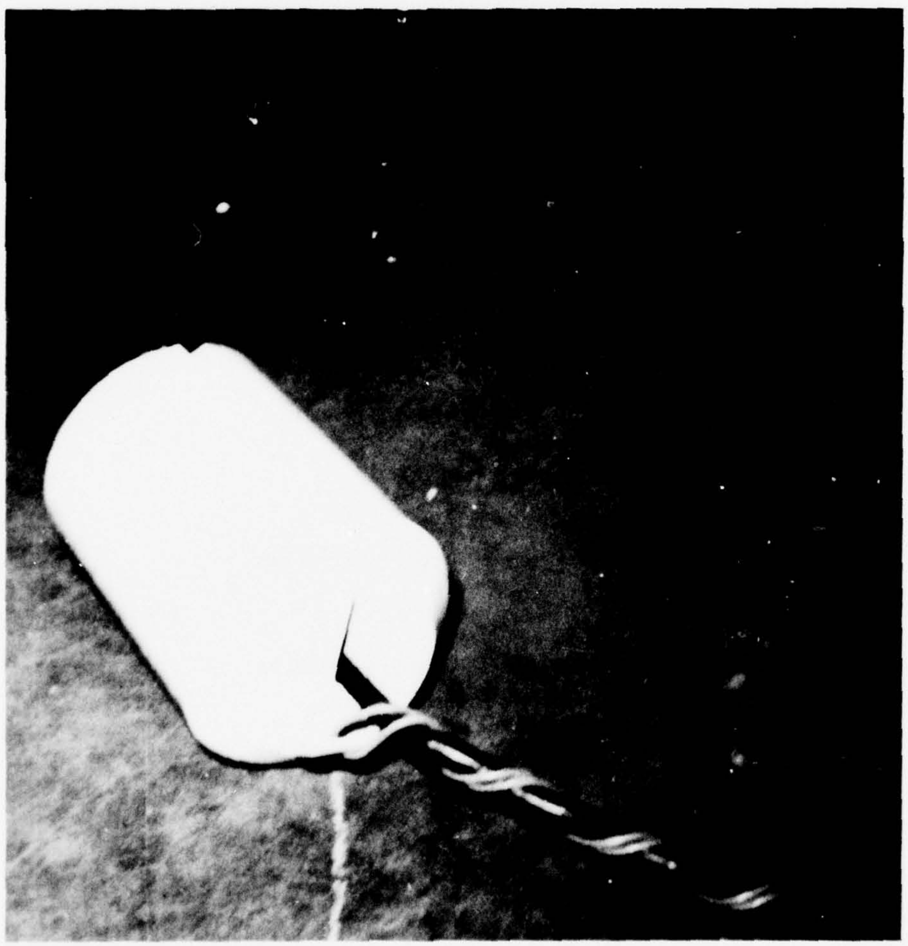

Figure 16. Array Buoyancy Attached to Cable

Figure 17. Array Tensioning Weight and Release System

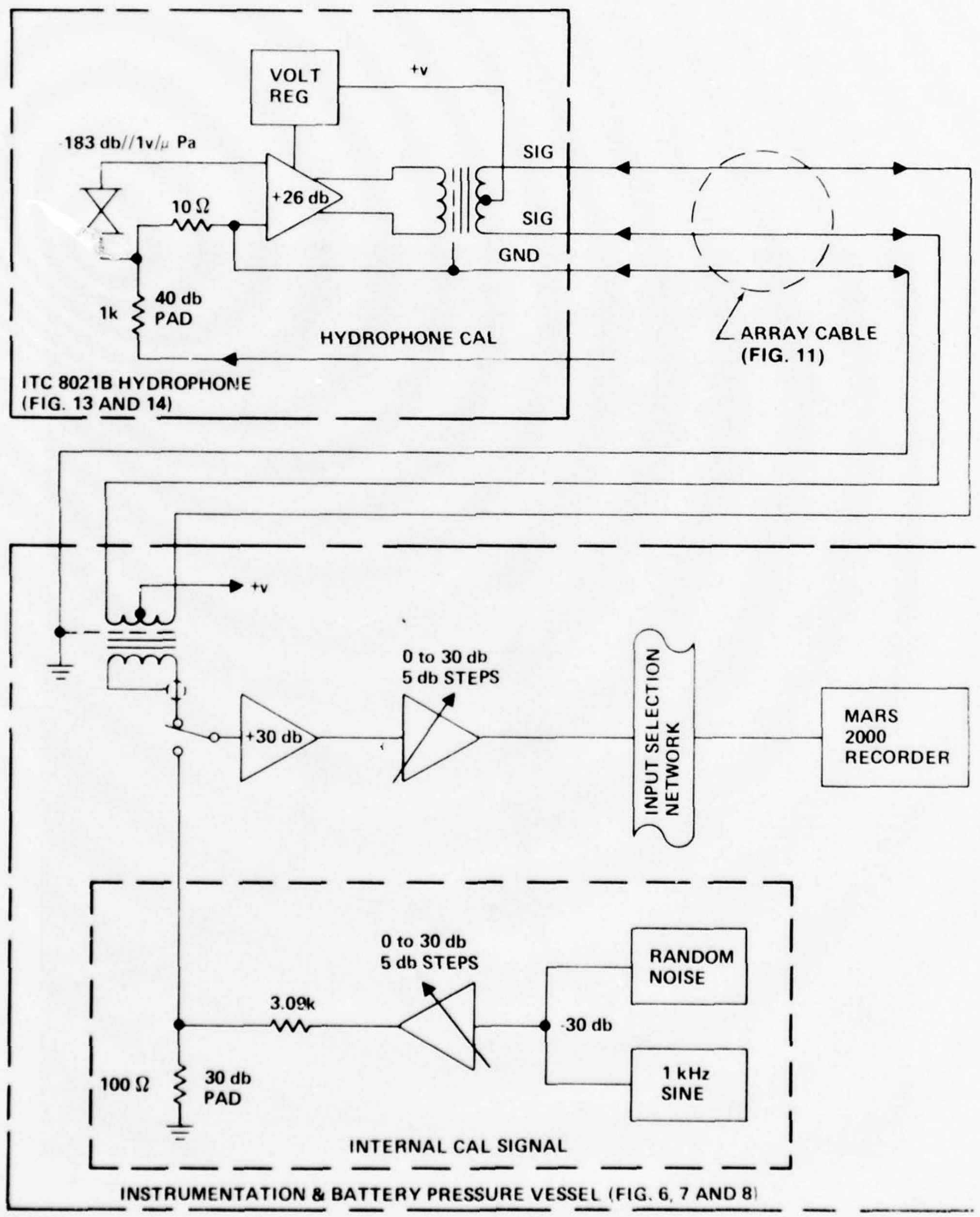

Figure 18a. AUTOBUOY Control and Sensor Systems, Block Diagram

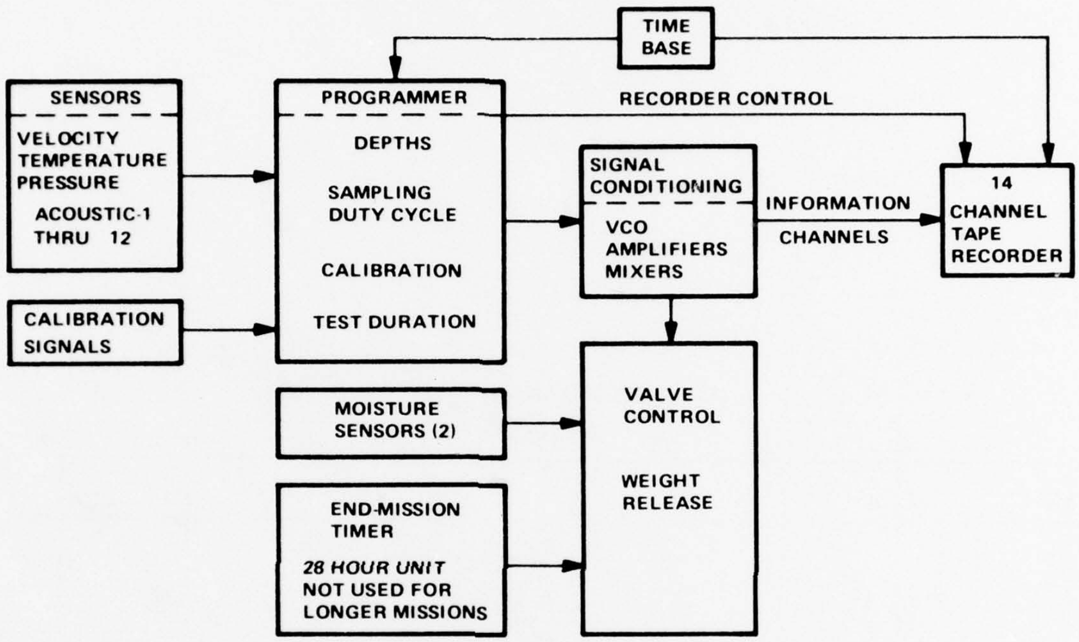

Figure 18b. AUTOBUOY Control and Sensor Systems, Block Diagram

Figure 19. Directional AUTOBUOY Launch and Retrieval System

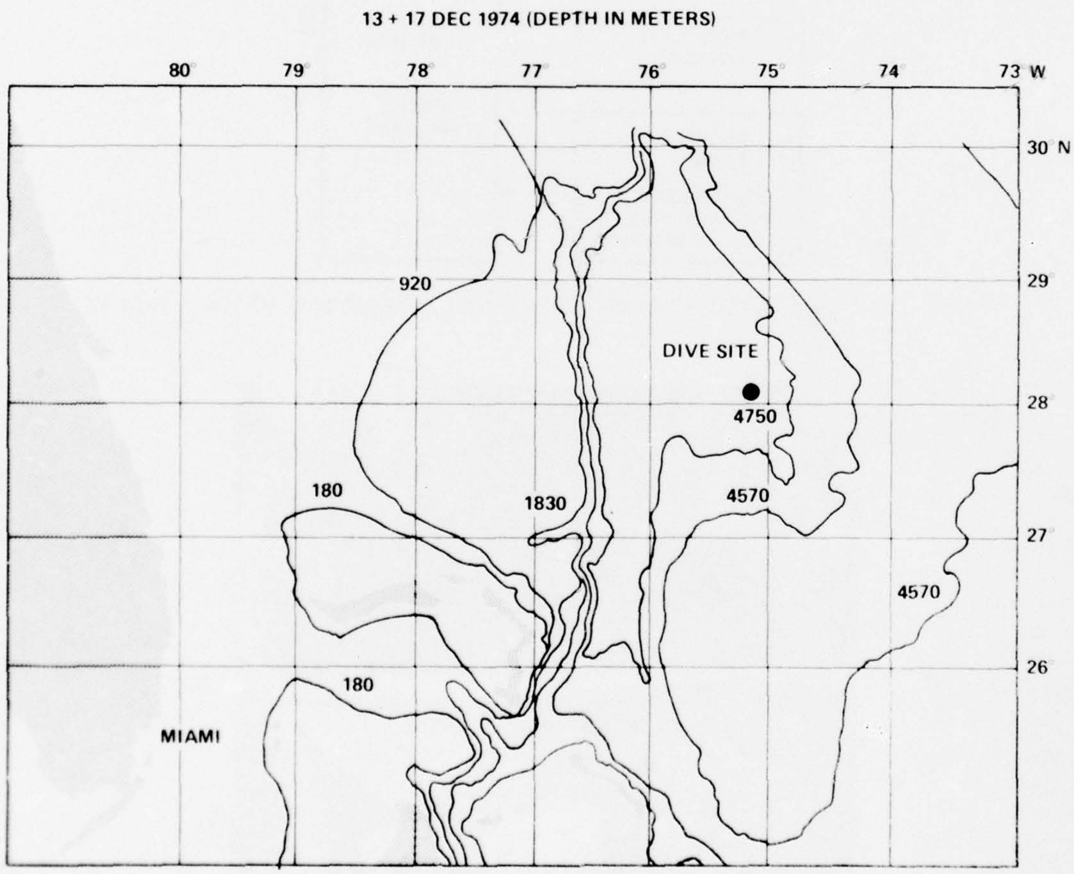

Figure 20. Directional AUTOBUOY Dive 1 and 2 Site

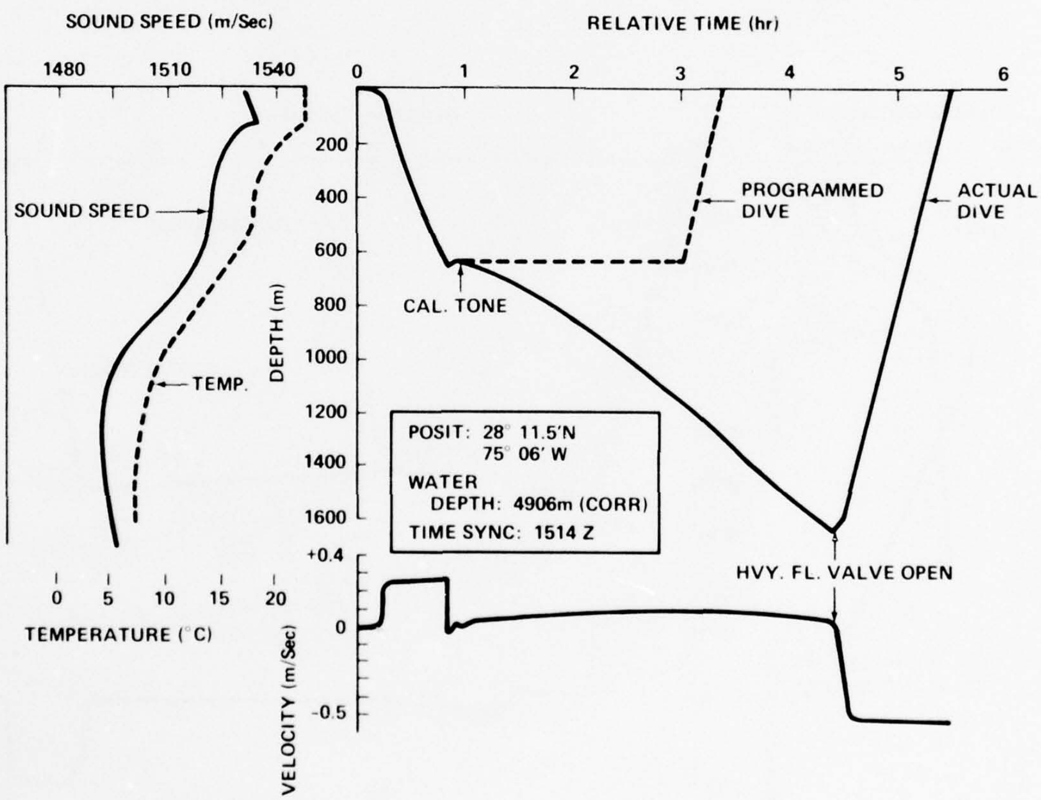

Figure 21. Directional AUTOBUOY Dive No. 1, 13 Dec. 74

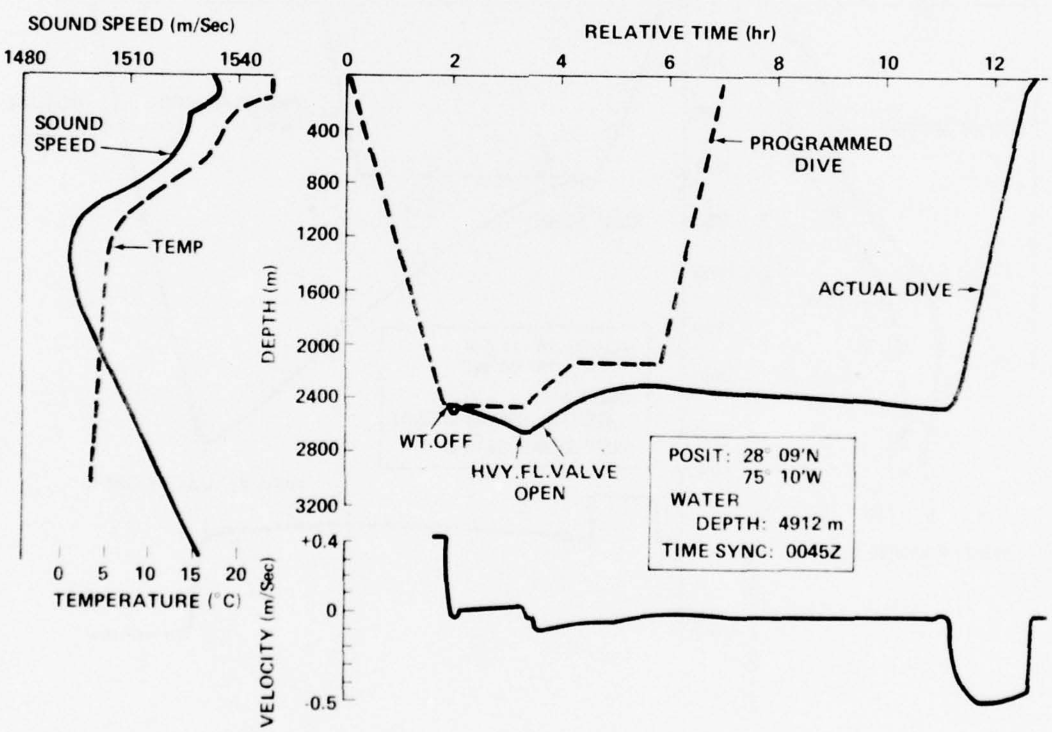

Figure 22. Directional AUTOBUOY Dive No. 2, 17 Dec. 74

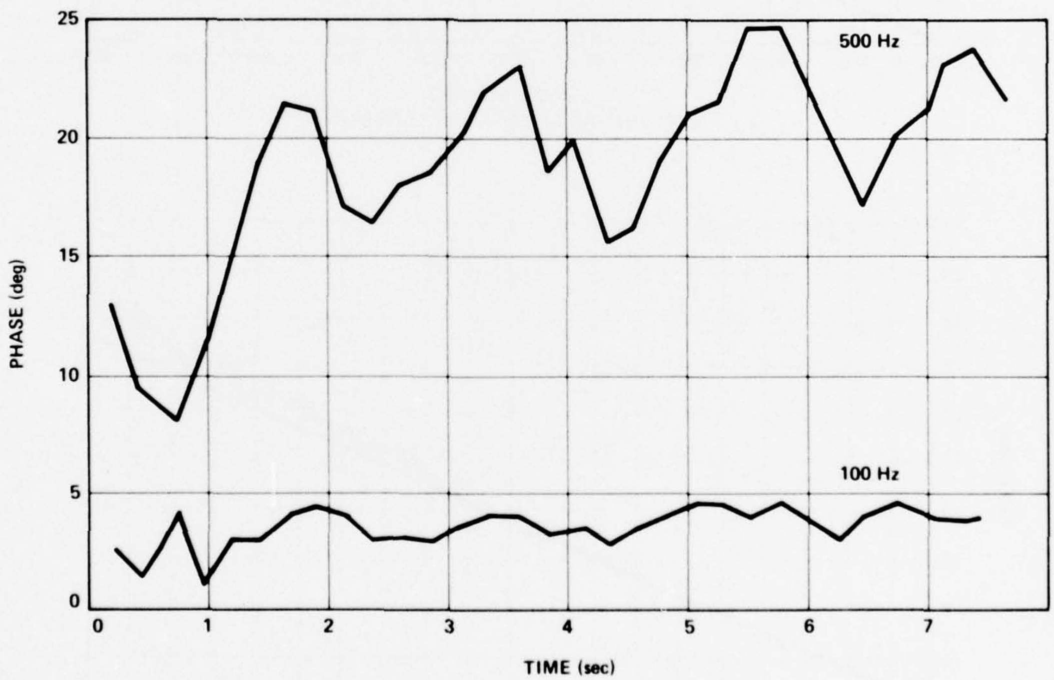

Figure 23. Phase Variation Caused by Tape Skew

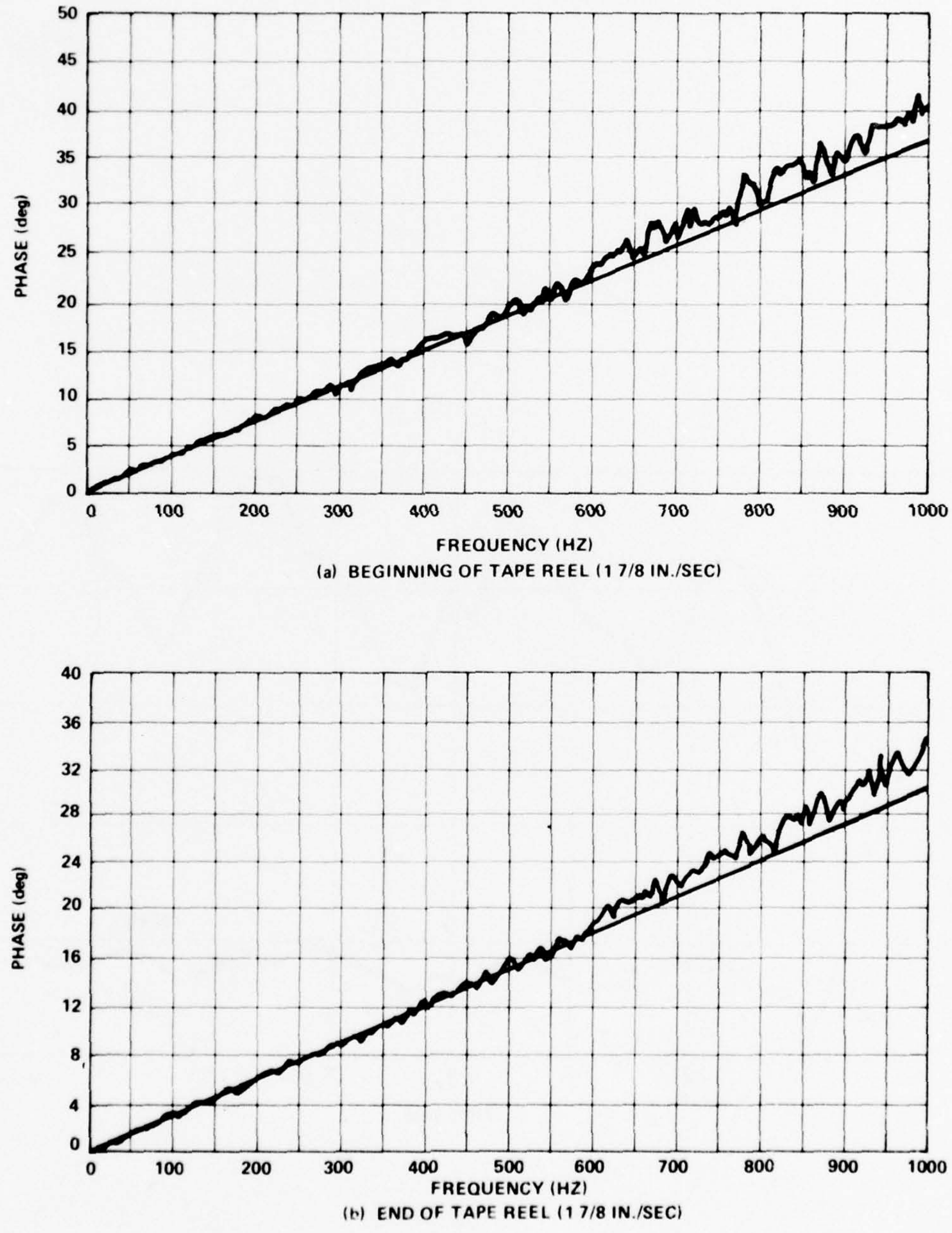

Figure 24. Phase Change and Location of Signal

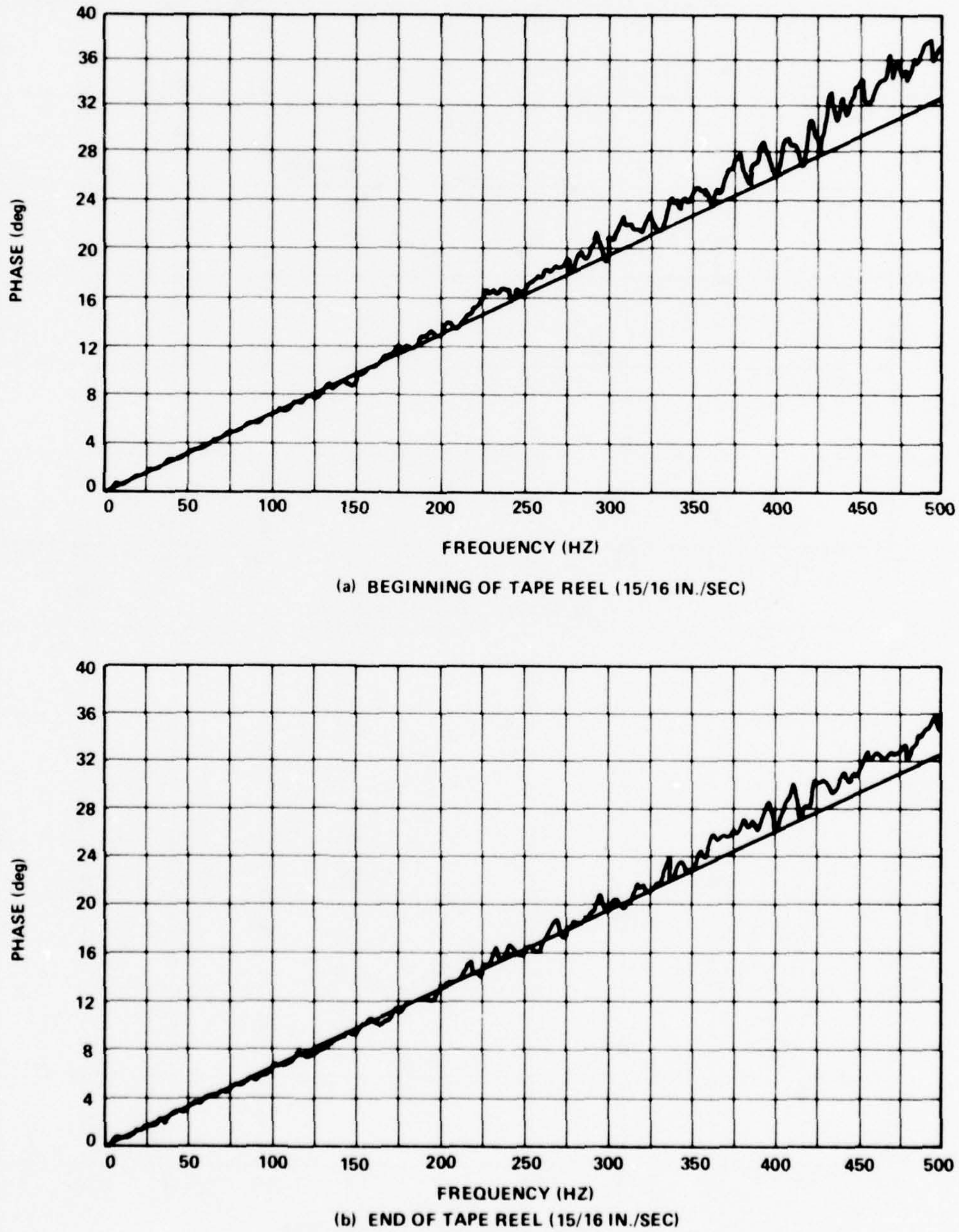

Figure 25. Phase Change and Location of Signal

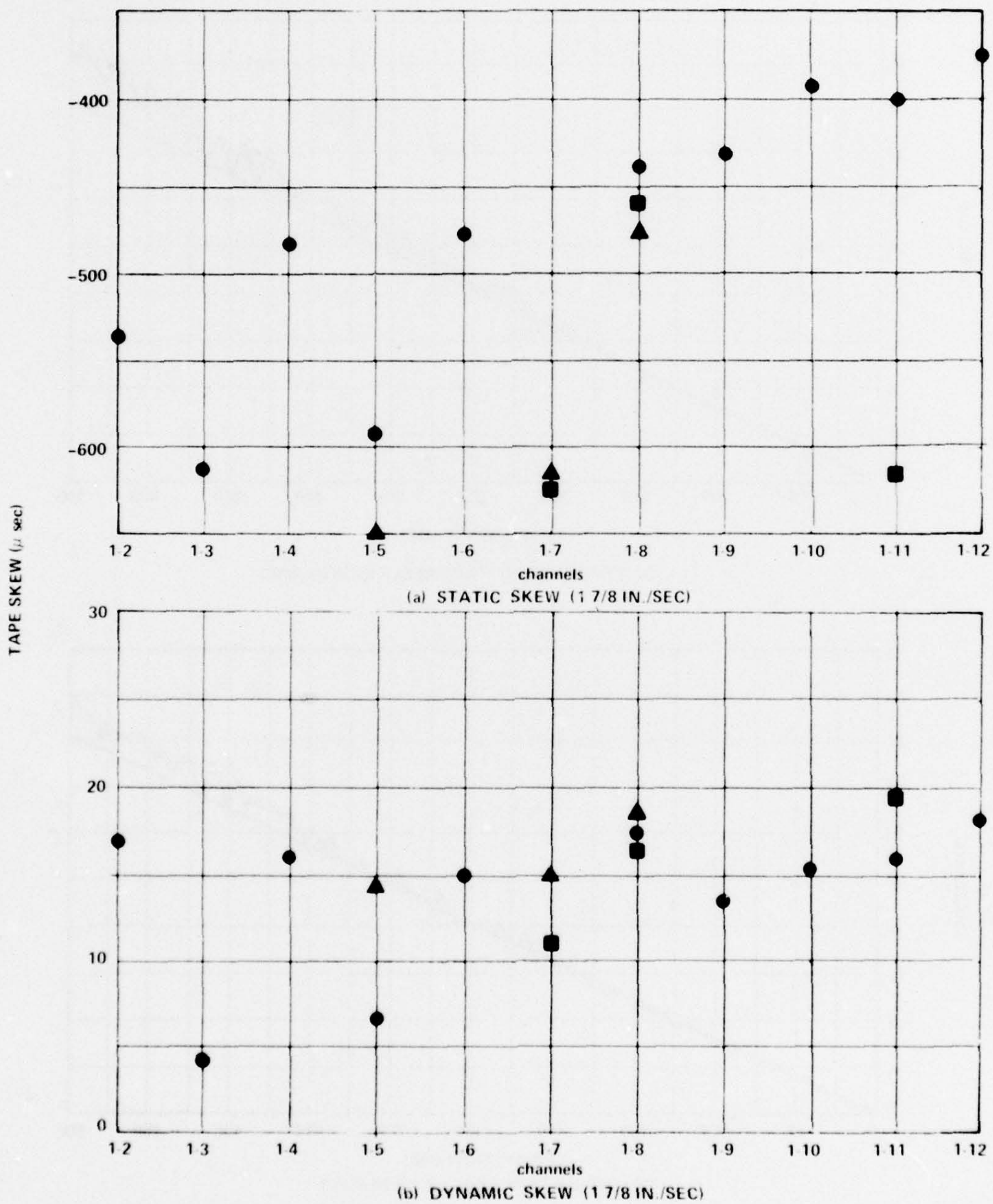

Figure 26. Measurement of Tape Skew

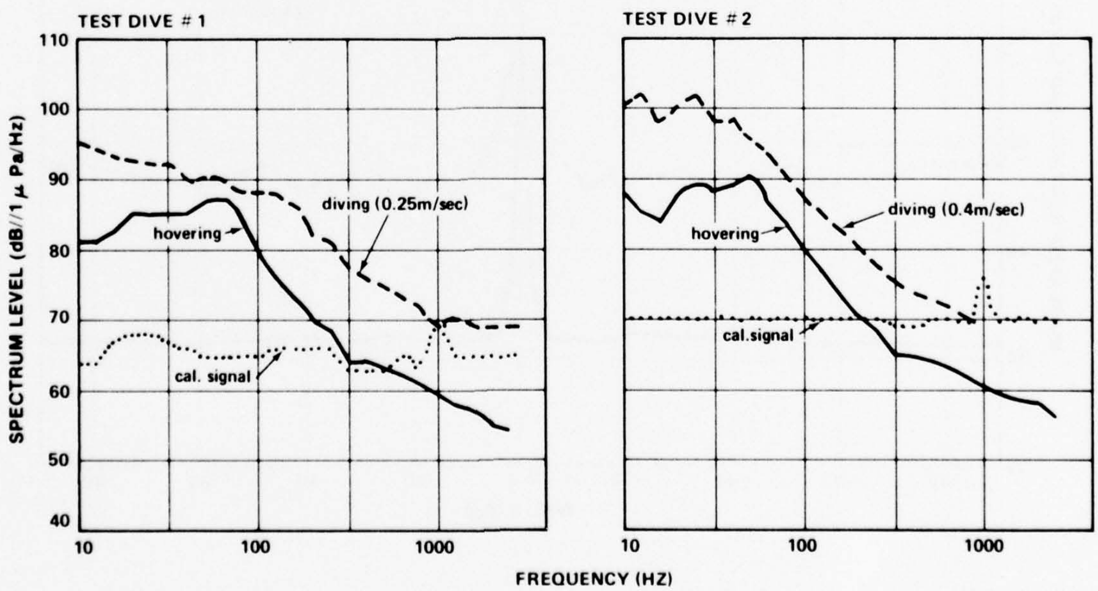

Figure 27. Ambient Noise Spectrum Level Measured By AUTOBUOY

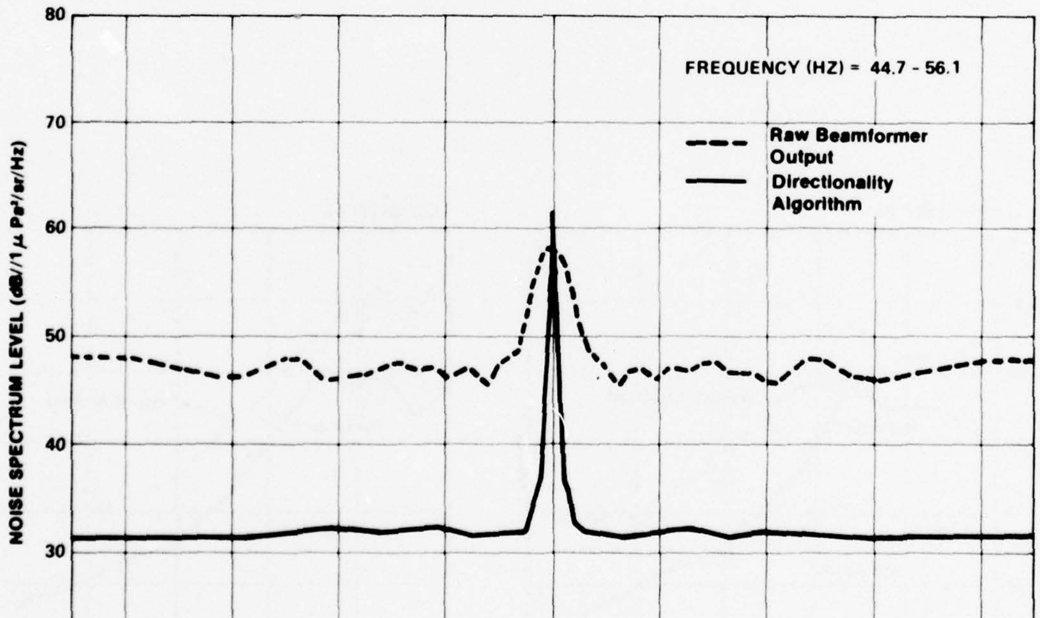

Figure 28. Directionality Functions for the Calibration Signal

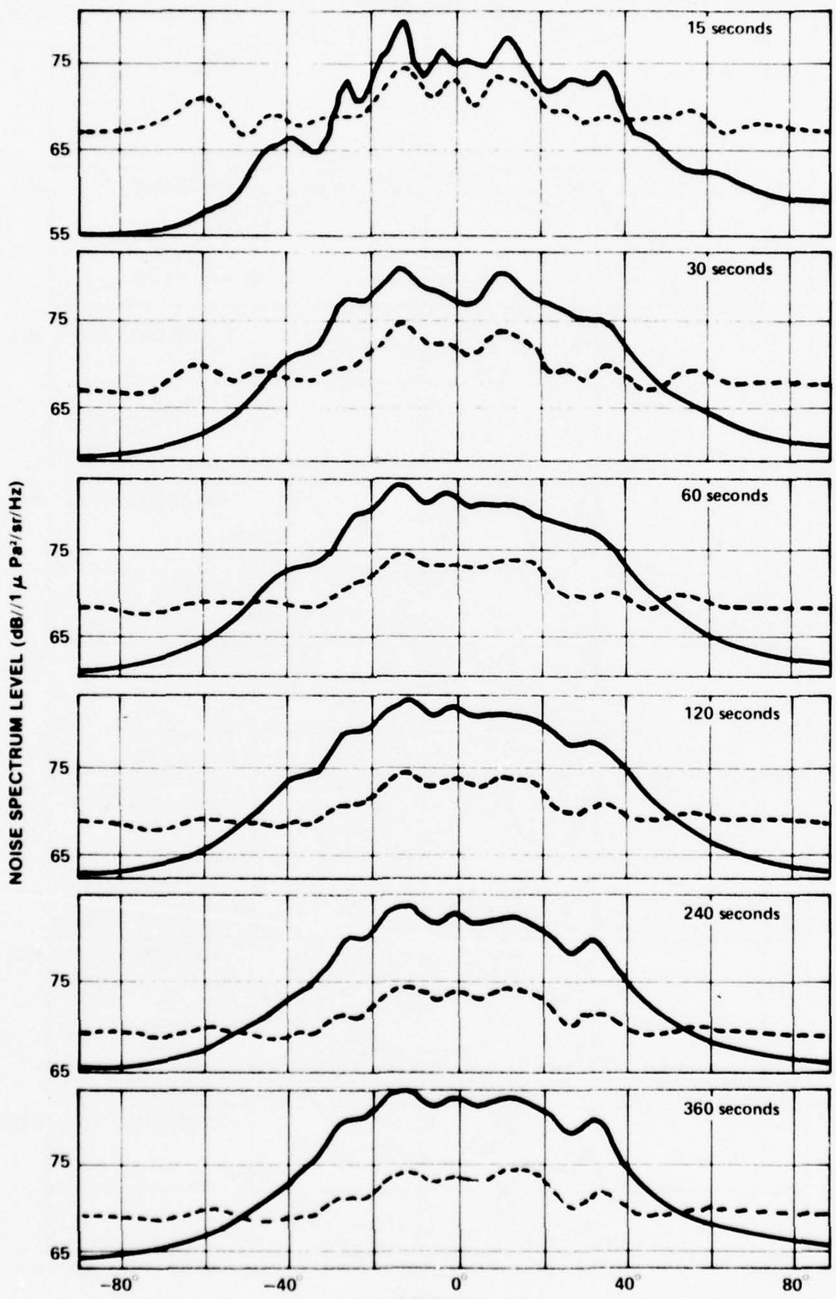

Figure 29. Stationarity of Ambient Noise Directionality

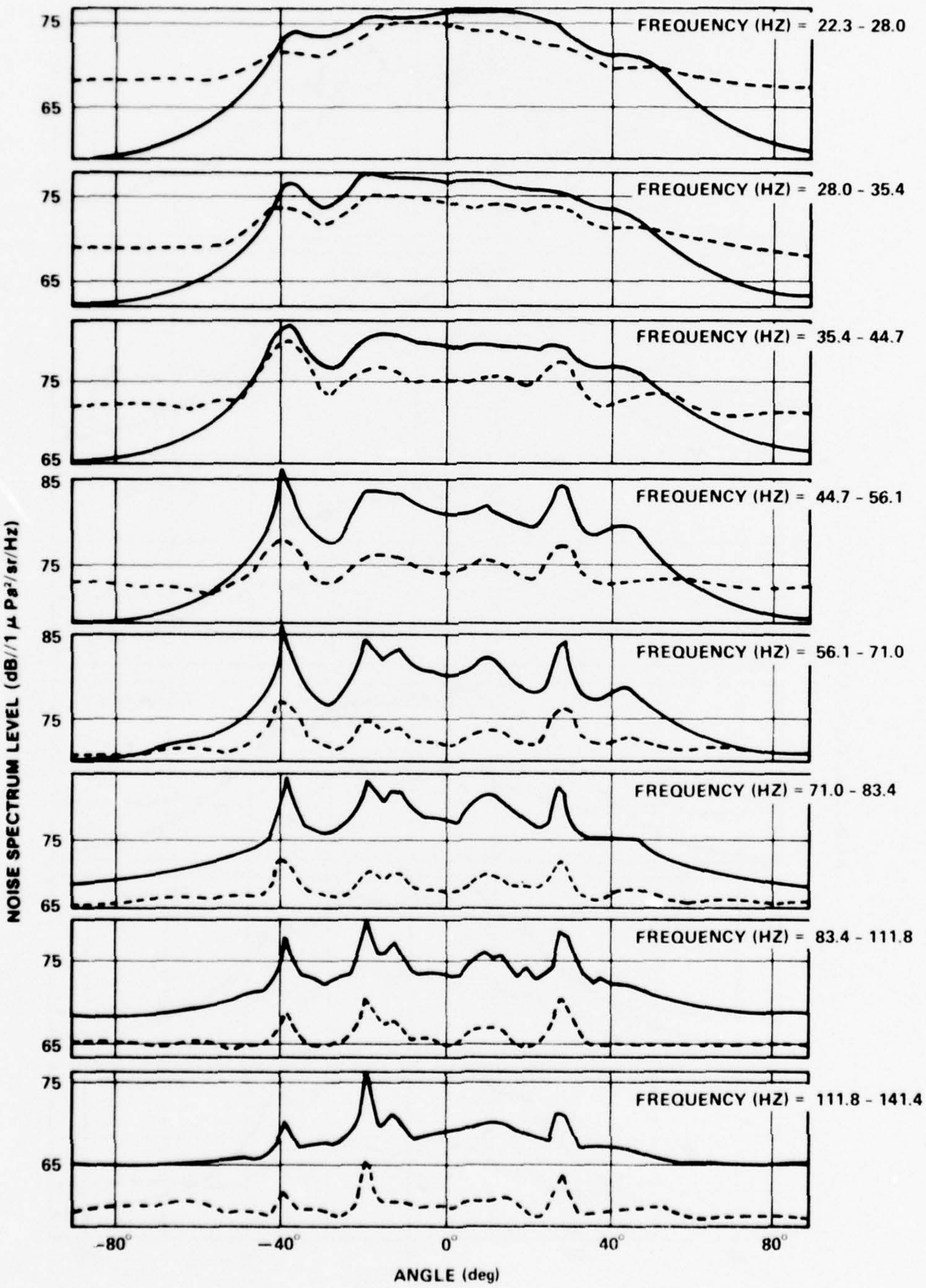

Figure 30. Ambient Noise Directionality in One-Third Octave Bands

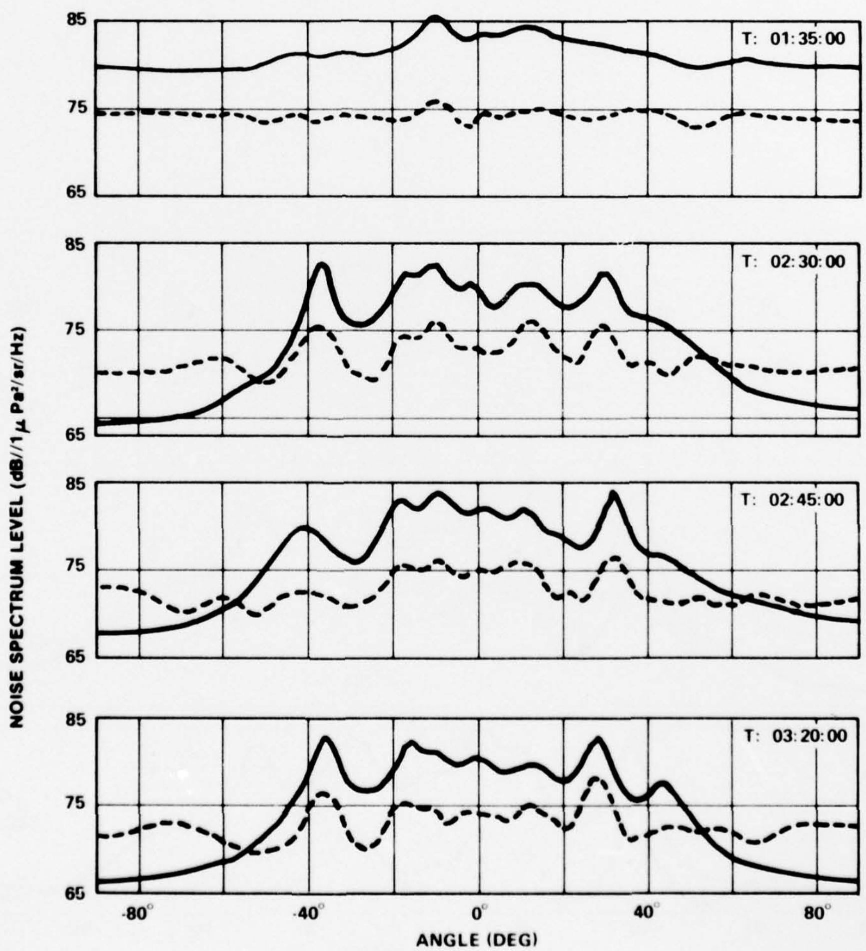

Figure 31. Long Term Variation of Ambient Noise Directionality

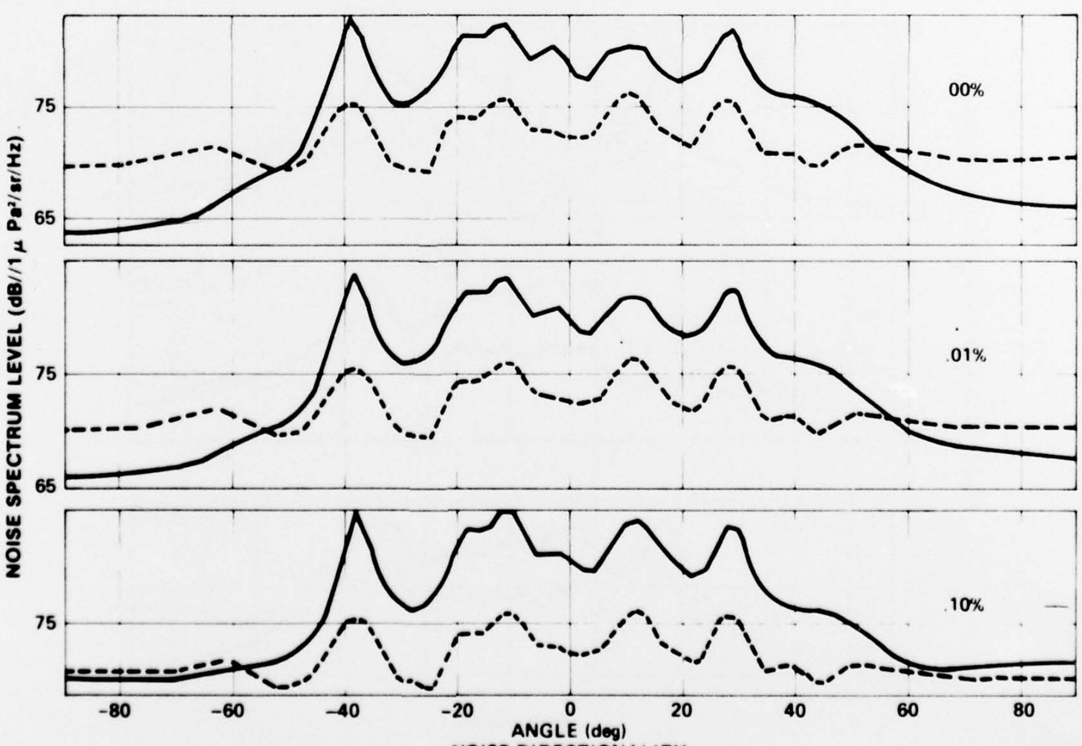

Figure 32. Effect of Uncorrelated System Noise

REFERENCES

1. R. S. Gozzo and R. L. Martin, AUTOBUOY, Present Capabilities and Planned Modifications, NUSC Technical Report 4505, 11 June 1973.

2. N. Yen, "Data Reduction for AUTOBUOY Array Ambient Noise Directionality Measurement," NUSC Technical Memorandum TA11-11-74, 21 January 1974.

3. "Operational Tests of Modified AUTOBUOY," NUSC Ser TA11-319, 15 November 1974.

4. A. H. Nuttall and D. W. Hyde, A Unified Approach to Optimum and Suboptimum Processing for Arrays, NUSC Technical Report 992, 22 April 1969.

5. R. L. Martin, "Large Aperture Highly Populated Array for Noise Vertical Directionality Measurements; Proposal for," NUSC Ser TA11-194, 3 July 1975.

APPENDIX A

EQUIPMENT SPECIFICATIONS

MOISTURE SENSOR

A two terminal conduction detector located in the instrumentation housing and control housing in a position to detect excessive moisture in the housing while the buoy is in its normal operating attitude.

END MISSION TIMER

Digital timer with a 48 hour range.

RECOVERY SYSTEM

Transmitter Batteries	Yardney Model LR-4
Xenon Lamp	Size "D" Alkaline Cells

BASIC TIMING GENERATOR

Crystal controlled oscillator

Frequency	1.0 kHz
Stability	$\pm$ 10 ppm

Output Characteristics

Sine Wave

1.0 $\pm$ 0.1 v p-p into 1 k Ω Load

Harmonic distortion less than 5%

MAIN POWER SOURCE

Yardney Balley Model LR-58-2

Yardney Balley Model LR-4-1

DEPTH RATE TRANSDUCER (VELOCITY), KESLTER INSTRUMENT CORP. MODEL 751M101

Sensitivity	5 V/lbf/in.^{2}/s
Output	$\pm$ 5V
Pressure range	0 to 10,000 lbf/in.^{2}g (0-68 MPa)
Operating temperature	28^{o}F to 100^{o}F (-2.3^{o}C to 38^o)
Power Requirements	$\pm$ 12V at 5 mA, nominal

PRESSURE TRANSDUCER, TABER INSTRUMENT CORP. MODEL 2401

Full scale output	3 Vdc
Temperature range	32^{o}F to 86^{o}F (0^{o}C to 30^{o}C)
Power requirements	24 V at 25 mA, nominal
Accuracy	$\pm$ 0.1% of full scale
Pressure range	.0 to 10,000 lbf/in.^{2}g (0-68 MPa)

TEMPERATURE TRANSDUCER, SEMCO INC. MODEL RT1028

Element	Platinum
Range	-300^{o}F to +500^{o}F (-149^{o}C to +260^{o}C)
Power requirements	20 mA, maximum
Pressure rating	10,000 lbf/in.^{2}g (68 MPa)
Repeatability	$\pm$ 0.01^{o}F ($\pm$ 0.005^{o}C)

SPECIFIC GRAVITY OF FLUIDS

Light fluid	0.88 to 0.9; 15.2 gal (57.5 ℓ)
Heavy fluid	1.4 to 1.5; 9.4 gal (35.6 ℓ)

TAPE RECORDER, "ASTROSCIENCE," MARS 2000

Reel Size	10.5 inch (27 cm)
Tape	4600 ft (1402 m), 1.0 mill, "E" Oxide
Weight	40 lbs (18.1 kg)
Dimensions (Rectangular)	16" X 12" X 5" (4dm X 3dm X 1.3dm)
Record Speed	1 7/8 in./sec & 15/16 in./sec
Flutter	1 7/8 in./sec 10.% pp
	15/16 in./sec 1.8% pp
Dynamic Skew (Max.)	1 7/8 in./sec 25 microseconds pp
	15/16 in./sec 50 microseconds pp
Signal to Noise	
Direct Record	1 7/8 in./sec 20 dB
	15/16 in./sec 15 dB
FM Record	1 7/8 in./sec 40 dB
	15/16 in./sec 35 dB
Frequency Response	
Direct Record	1 7/8 in./sec 400 Hz to 31.25 kHz
	15/16 in./sec 400 Hz to 15.625 kHz
FM Record	1 7/8 in./sec DC to 2.5 kHz
	15/16 in./sec DC to 1.25 kHz
Power Requirements	+25 V to +30 V
	115 Watts Nominal
Operating Temperature	-65°F to 160°F (-54°C to +71°C)

HYDROPHONE ITC-8021B

Pressure range: 0 to 10,000 $lbf/in.^2g$ (0-68 MPa)

Temperature Range: 32^oF to 104^oF (0^oC to 40^oC)

Frequency response: ± 2 dB, 5 Hz to 4,000 Hz

Maximum sensitivity change over temperature range: $\pm$ 1/2 dB

Maximum sensitivity change over pressure range: $\pm$ 1/2 dB

Directivity: Omnidirectional, $\pm$ 1/2 dB in all directions over frequency range of 5 Hz to 2 kHz. ± 2 dB from 5 Hz to 5 kHz

System noise: 10 dB less than Knudsen SSO over the frequency range

Output level: Minimum undistorted level, 1 VRMS over the frequency range

Acceleration cancelling: Has a response 20 dB below a non-canceling hydrophone for accelerations up to 1 g in all directions

Element receive sensitivity: -183 dB//1V/μPa minimum

Preamplifier

Voltage gain: 26 dB

Power requirements: 24 VDC ± 4 VDC at 10 ma maximum

Frequency response: $\pm$ 1/2 dB over frequency range of 5 Hz to 5,000 Hz.

Output: Transformer to balanced line. Phase shift, less than 5 degrees over bandwidth. Shielding, electro-static 40 dB. Balance, -60 dB balance error between half-windings.

Calibration provisions: 40.$\pm$.1 dB pad in hydrophone. Input to calibrate circuit through 4 pin connector.

Pressure-proof housing: All electronics to be pressure insensitive over the pressure range. No pressure-proof housing for the electronics.

Preamp Circuit Protection: The preamplifier circuit will be protected from possible damage due to high voltage generated by shock, overload, polarity reversal, and shorted output.

Power Supply noise rejection @ 60 Hz, 60 dB

Hydrophone matching: All hydrophones in the array shall be matched to within:

(1) Acoustic sensitivity vs. frequency: $\pm$ 1/2 dB over the frequency range

(2) Phase matched to:

5^{o} total 20 Hz to 5 kHz
10^{o} total 10 Hz to 20 Hz
20^{o} total 5 Hz to 10 Hz

Hydrophone mechanical:

Weight: 2.76 pounds in water, including protective cage

Length: 7.80 inch. maximum, not including cable and connector

Outside: Hydrophone molded section 3" maximum; protective cage 3 3/4" diameter maximum

Material: Molded neoprene boot

VOLTAGE CONTROLLED OSCILLATOR

Gulton Model LM1-9064

Temperature	3,900 Hz Center Frequency
Velocity	7,350 Hz Center Frequency
Pressure (Depth)	14,500 Hz Center Frequency
Input Voltage	$\pm$ 2.5V
Output Voltage	0 to .5 VRMS
Center Frequency	$\pm$ 1% dBw Max

Center Frequency Deviation	± 7 1/2%
Distortion	1%
Linearity	± 0.25% dBw Max
Power	28V ± 8V at 3.5 mA Max

APPENDIX B

CORRECTIVE DESIGN ACTION

DIRECTIONAL AUTOBUOY MODIFICATIONS

During the operational sea test of Directional AUTOBUOY (Dec. 1974), it was found that electronic and mechanical revisions would be required to improve the performance reliability and operational efficiency of the buoy system. The problems and corrective design actions are listed below:

1. The buoy was found to be negatively buoyant by approximately 2.2 kg (4.5 lb).

CORRECTIVE ACTION: A section of syntactic flotation 61 cm in diameter X 20 cm thick was added to the center section of the buoy. This provides a net 18 kg of buoyancy. When the array with its weight is added, this buoyancy ensures adequate tension in the array without using excessive discharging of light and heavy fluids.

2. The performance data showed that the buoy drifted deeper than the reference hover depth at a very slow rate; also the heavy fluid valve was not operated by this depth overshoot. It was determined that the malfunction was due to drift of the output signal of the Solion tetrode device which provides the voltage for the reference depth.

CORRECTIVE ACTION: New Solion devices are not available; the manufacturer of the device stopped production in 1970.

A new circuit was added to eliminate the Solion. This circuit takes the dc output of the pressure transducer and stores the data by means of a A/D converter; these digital data are then restored to a "dc" level by a D/A converter and supplied to the valve control circuits.

3. The buoy failed to complete a programmed station change from 2650 m to 2133 m, because the buoy was not able to release enough heavy fluid to reach the new hover depth of 2133 m.

CORRECTIVE ACTION: Eliminated the valve R/C timing circuits and replaced them with a digitally controlled velocity ascent system. The new system allows selection of ascent rates of 3 cm/sec to 30 cm/sec.

4. The internal acoustic calibration timing circuits did not have sufficient range or reliability.

CORRECTIVE ACTION: Eliminated present R/C timing circuits with digitally controlled circuits which allow selection of time between 10 and 900 seconds in 10-second steps.

5. The "End Mission" timer could not be synchronized with the start of a mission.

CORRECTIVE ACTION: Eliminated the present mechanical timer. Added two fine position switches which are connected to the output of the hours section of the basic timing generator. When mission elapsed time is reached (after the "Time Sync" has passed), a signal is generated to end the mission.

6. Individual hydrophone power was not fused.

CORRECTIVE ACTION: Two fuses were added to each hydrophone power circuit (+12V & -12V); this was done on the post amplifier boards.

7. Modification of recorder control circuits to permit operation of the programming system without requiring the recorder being energized.

CORRECTIVE ACTION: A switch and indicator lamps were added to the recorder control panel.

8. Modify the front structure mechanically.

CORRECTIVE ACTION: Relocated and replaced eight socket head screws with hex head bolts. Relocated and protected weight release coil assembly and electrical input leads.

9. Modify start circuit to allow the buoy timing to be started from an external source (T.C.G.).

CORRECTIVE ACTION: Revised the external test point input to accept a pulse which is connected to the "Time Sync" mode.

APPENDIX C

EXCERPT OF SENIOR SCIENTIST LOG FOR SEA TEST
USNS BARTLETT - DEC 1974

11 Dec - Ballasting measurements - Directional AUTOBUOY in water with small boat alongside tethered to system. Found AUTOBUOY to be negatively buoyant.

- Returned equipment on-board and replaced 13 quarts of heavy fluid with sea water to ensure it being buoyant. Equipment returned to water tethered to small boat.

- Results indicate that Directional AUTOBUOY is 16 kg less buoyant than planned. This will be corrected by an additional section, 15 - 30 cm long, to the syntactic foam cylinder. (15 cm yields 17 kg of increased buoyancy). For the purpose of these tests, syntactic foam clumps will be tied to the "nose" of AUTOBUOY to make up the present buoyancy deficiency.

- AUTOBUOY returned to ship and rigged for pressure test. With Astroscience tape deck replaced by equivalent weight inside instrument sphere, equipment was lowered by wire to 1525 m depth ($\sim$15 MPa) then pulled back to the surface where it was inspected for leaks. No moisture was detected in either the instrument sphere or in the programming sphere.

12 Dec - The array of hydrophones with buoyancy (13 blocks) and a 13 kg weight attached was deployed and tethered to the small boat. It was determined that the array was very close to being neutrally buoyant. It appears, however, that some redistribution of buoyancy will be required.

- Remainder of day spent preparing system for first free dive. Astroscience Recorder was placed in instrument sphere, program for one-depth, 600 m (2000 ft) dive was set, system was completely groomed and operational functions checked out. Two syntactic foam clumps (spare buoyancy elements for the array) were modified and rigidly attached to the front end ("nose") of AUTOBUOY.

13 Dec - 1519Z - AUTOBUOY in water at 28^{o} 11.5' N, 75^{o} 06' W (Loran A) Water Depth 4906 m (corrected)

- Ship remains at deployment point. No attempt at ship quieting.

- At 1546Z and every 1/2 hour later, 3 rifle shots were fired into the water at 5 second intervals to be used as a check on depth sensor in Directional AUTOBUOY.

- Dive programmed to last 3 1/2 hours.

- 2045Z equipment on surface 2 hours late.

- 2145Z AUTOBUOY on board.

- 2235Z ARRAY on board.

- Retrieval was complicated by the retrieving line tangling with the array. This was probably due to AUTOBUOY surfacing at a faster rate than the buoyant line.

- AUTOBUOY went to the 600 m depth as planned, hovered, and then started to slowly descend deeper at 7.5 cm/sec. The heavy fluid valve did not receive the command to release fluid by the pressure sensor nor did it receive the command at the two hour recording mark. The heavy fluid valve opened when the buoy was at a depth of 1675 m.

14 Dec - Day was spent plotting results and working on electronics to determine the cause of failure. The battery contacts on the depth reference circuit were found to be bad. This is why changes in depth and high depth rate did not signal the heavy fluid valve to open.

15 Dec - Weather not satisfactory for deployment. Seas varied from sea state 4 to sea state 5 moderating somewhat in the evening.

16 Dec - Weather delayed deployment (sea state 3-4).

- Continued checking electronics circuits.

17 Dec - 0045Z AUTOBUOY launched at 28° 08.8' N 75° 10.3' W (SATELLITE) Water depth 4912 m (corrected).

- 0320Z BARTLETT at "QUIET SHIP" condition (gas turbine) at 5 nmi from deployment site. Three rounds of rifle shots 5 seconds apart were used at each of 3 intervals between 0300 and 0400Z.

- AUTOBUOY was programmed to return to surface at 0800Z but didn't.

- 1325Z AUTOBUOY on surface.

- 1525Z Entire system on board. Heading for Fort Lauderdale.

18 Dec - Cause of problem appears to be that pressure excess sensor command was not received by the heavy fluid valve. The heavy fluid valve did open when the recording period ended at the first depth (2438 m); however, the buoy had descended to 2652 m by this time. Fluid could not be released fast enough to bring the buoy to the second depth. (The buoy did change depth approximately 400 m.)

- Having not detected that second depth, the system did not continue in its program but rather maintained position (with a slow descent) between 2255 m and 2438 m until the heavy fluid was released by the end of mission time.

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